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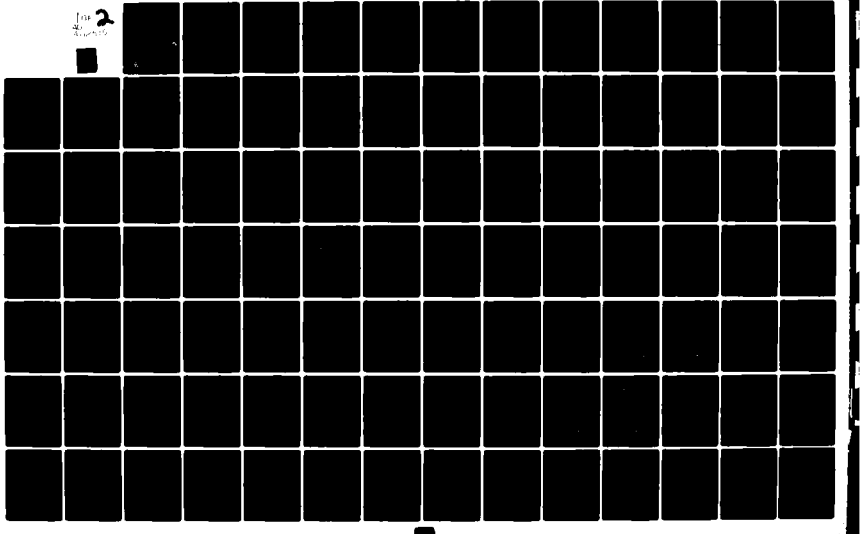

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A CLIMATOLOGY OF THE REFRACTIVE INDEX STRUCTURE FUNCTION PARAMETER, C_n^2, IN THE NORTH ATLANTIC OCEAN REGION

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JANUARY 1982

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The optical refractive index structure function parameter, C_n^2, describes the effects of turbulence on optical propagation. Surface boundary layer turbulence models are used to calculate monthly mean values and standard deviations of C_n^2 in the North Atlantic Ocean. C_n^2 statistics are presented as isopleths of mean values and standard deviations for day, night, and diurnally averaged values.

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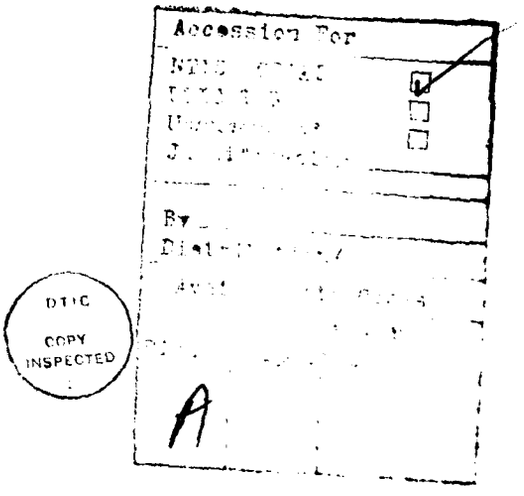

1. INTRODUCTION

The shipboard operation of optical laser systems is degraded by turbulence in the marine planetary boundary layer (MPBL). The refractive index structure function parameter, C_n^2, is a measure of the turbulent fluctuations of refractive index over small distances and is the turbulence parameter related to optical system performance. C_n^2 is defined by:

$$C_n^2 = \overline{[n(x+r) - n(x)]^2} \; r^{-2/3}, \qquad (1)$$

where n(x+r) and n(x) are the refractive indices at points separated by a short distance r. The overbar represents an average value over a spatial region or a time interval. Refractive index fluctuations cause a loss of coherence in a laser beam, a broadening of the beam, and a reduction in power focused on a target.

This climatology presents the means and standard deviations of C_n^2 values for the North Atlantic Ocean region. Locales characterized by large C_n^2 values are identified and indicate areas where optical system performance will be degraded. The diurnal variation of C_n^2 also is presented.

2. METHOD

Surface layer turbulence is generated by the fluxes of heat, momentum and moisture in the sea surface boundary layer. The values of these fluxes have been related to commonly observed meteorological variables by the development of surface layer scaling laws. A model using these laws, together with modifications for use of the model in the MPBL, has been described by Burk et al. (1979). A modified form of the model is included as Appendix A.

The meteorological variables required for the model are:

U - wind speed, usually taken at 10 m height

T - air temperature

T_s - sea surface temperature

q - specific humidity, taken at 10 m height

3. DATA

The data base for this study was a subset of the Fleet Numerical Oceanography Center's Consolidated Data Set of marine surface observations. Eleven years of data (1963-1973) were extracted and processed for this analysis. This period was selected to avoid the inclusion of low precision merchant vessel data collected before 1962. Husby (1980) cites such data as a contributor to erroneous heat flux computations.

The accuracy of the data base can be evaluated by comparing simultaneous observations from merchant vessels and ocean station weather ships. Since merchant reports dominate the data base it is important that these observations be reliable. Bunker (1976) found good agreement between means of wind speed, sea surface temperature and air temperature as reported by merchants and weather ships when at least 500 observations are included per average. The uncertainty in the determination of the heat flux can be expected to be about 10% in such cases. This uncertainty increases as the number of observations falls below 500. Mean values of C_n^2 were calculated for each 1° latitude by 1° longitude Marsden subsquare in the study area. Along the major shipping lanes at least 500 observations per month and subsquare generally were reported. Outside these routes the number of reports declined greatly.

Several quality control checks have been made to improve the reliability of the observations. Reports indicating supersaturated conditions were discarded along with air temperatures outside the

range of $\pm$50°C. Reported dew point temperatures were compared to values computed from reported wet and dry bulb temperatures and the report discarded if the disagreement was $\geq$1°C. Reported air-sea temperature differences were similarly screened. Sea surface temperatures < -8.0°C were eliminated as were sea surface temperatures that deviated from a running mean for each month and subsquare by more than 9°C.

All observations were assumed to have been made at a height of 10 m since actual levels are not reported. The effect of differing heights is probably less significant than other observational errors. A minimum wind speed of 1 meter per second was allowed. Reports of calm conditions were modified accordingly.

Finally, C_n^2 was defined as zero when the air and sea surface temperatures were equal.

The data successfully screened were grouped and analyzed in three categories, daytime, nighttime and all times. Daytime was defined to be from 0601 to 1800 local standard time.

4. RESULTS

The isopleths of mean C_n^2 values are presented for the twelve months for day and night (Figure 1-12), daytime only (Fig. 13-24) and for nighttime only (Fig. 25-36). The units are $m^{-2/3} \times 10^{15}$. Standard deviations are shown in Figures 37-72.

The most striking feature of the figures is the strong influence of the Gulf Stream on the turbulence values. The heat flux from the warm sea surface to the colder air is accompanied by higher levels of turbulence than in surrounding areas of colder water. The maximum values of turbulent intensity over the Gulf Stream occurs during winter. This corresponds to the strong heat flux from the warm sea surface to the cold winter air of continental origin.

The diurnal variation of turbulence appears to be greatest during the summer in the area southeast of the Azores. This is an area where there is a small annual variation of sea surface temperature and wind speed. However, insolation does differ between night and day, and this contrast is largest during the summer months. This point leads us to conjecture that the apparent diurnal variation of turbulence levels between the Azores and the African coast is primarily due to ship insolation, and does not indicate the actual variability of C_n^2 in the MPBL. If this is correct, then the isopleths based only on nighttime data most accurately represent the distribution of mean C_n^2 values for the region.

FIGS. 1-72 ARE PRESENTED AS A GROUP BEGINNING ON P. 22.

APPENDIX A

C_n^2 Turbulence Model

This appendix describes a sequence of calculations to compute the refractive index structure function parameter, C_n^2, from shipboard measurements of air temperature, sea surface temperature, wind speed and specific humidity. The algorithm is a modification of a preliminary model described by Burk et al. (1979) who concluded that the surface layer scaling laws used to predict C_n^2 are accurate to a factor of two and that the accuracy of the shipboard observations introduces the same order of uncertainty into C_n^2 results.

A.1 Refractive index structure function parameter, C_n^2

Since refractive index is related to temperature, moisture and pressure, the fluctuations of the refractive index that compose C_n^2 are caused by fluctuations in these variables. The effect of pressure variations can be neglected while variations of temperature and moisture are described by the temperature structure function parameter, C_T^2, the moisture structure function parameter, C_e^2, and the temperature/moisture correlation parameter, C_{eT}. These component structure parameters are related to C_n^2 by:

$$C_n^2 = B_1 C_T^2 + B_2 C_{eT} + B_3 C_e^2 T \qquad \text{(A-1)}$$

where B_1, B_2 and B_3 are functions of temperature, pressure and vapor pressure.

Over the range of normally observed values of these structure parameters, C_T^2 is the largest contributor to C_n^2. Over land, where moisture sources are relatively unimportant, the contributions of C_e^2 and C_{eT} are negligible. Over water the contributions of these structure parameters are significant. To calculate C_n^2 in the marine planetary boundary layer (MPBL), it is necessary to calculate C_T^2 and modify it for the contribution made by moisture fluctuations.

In developing the modification used in this model, Wesely (1976) expands the definition of the refractive index structure parameter to provide C_n^2 as a function of the component structure functions and covariances,

$$C_n^2 = C_T^2\left(\frac{A_1 P}{T}\right)^2 \alpha_v^2;\ \alpha_v^2 = 1+2r_{eT}\left[\frac{(1-A_2/A_1)C_e T}{PC_T}\right]+\left[\frac{(1-A_2/A_1)C_e T}{PC_T}\right]^2 \quad \text{(A-2)}$$

where T is the mean layer temperature in K, P is the mean layer pressure in mb,

$A_1 = 78.7\cdot10^{-6}$K mb^{-1}, $A_2 = 66.7\cdot10^{-6}$K mb^{-1} and $r_{eT} = \frac{C_{eT}}{C_e C_T}$.

For this analysis it was assumed that e and T are perfectly correlated and $r_{eT} = 1$. Thus,

$$C_n^2 = C_T^2\left(\frac{A_1 P}{T}\right)^2\left(1 + \frac{0.03}{B}\right)^2 \quad \text{(A-3)}$$

where B is the Bowen ratio defined below.

A.2 Temperature structure function parameter, C_T^2

In the surface layer, dimensional arguments first introduced by Monin and Obukhov can be used to relate C_T^2 to a temperature scale, T_*; a height, z; and a stability function, g(z/L). Wyngaard et al. (1971) derived a semiempirical relationship of these parameters,

$$C_T^2 = T_*^2 \, z^{-2/3} \, g(z/L) \qquad \text{(A-4)}$$

where L is the Monin-Obukhov length scale.

A.3 Stability Function in C_T^2

Using a set of careful observations over uniform terrain in Kansas, Wyngaard et al. (1971) have empirically determined the function g(z/L) from measurements of C_T^2 and the scaling parameters L and T_*. The results have been tested over water by Friehe (1977) and Davidson et al. (1978). The following expressions are used in this analysis,

$$\begin{aligned} g(z/L) &= 4.9(1-7z/L)^{-2/3} \qquad (L \leq 0) \\ g(z/L) &= 4.9(1+2.75(z/L)^{2/3}) \quad (L>0). \end{aligned} \qquad \text{(A-5)}$$

A.4 Scaling functions in the surface layer

The Monin-Obukhov theory describes the surface layer using non-dimensional atmospheric variables. Physical variables of length, z; wind speed, U; temperature, T; and specific humidity, q; are made non-dimensional by defining a scaling length, L; a scaling speed, U_*; a scaling temperature, T_*; and a scaling humidity, Q_*. The non-dimensional parameters describe the fluxes of momentum, heat, and humidity in the surface layer.

A.5 Monin-Obukhov length, L

In a dry atmosphere the characteristic length L_{DRY} is taken as the Monin-Obukhov length,

$$L_{DRY} = \frac{T\, U_*^2}{g\, k T_*} \tag{A-6}$$

where T is mean surface layer temperature in K, g is acceleration of gravity, and k is the von Kármán constant. In unstable air buoyancy generated turbulence dominates at levels above -L, while mechanical turbulence dominates much below -L. The length is corrected for moisture by using the Bowen ratio B,

$$L = L_{DRY}\left(1 + \frac{.07}{B}\right)^{-1} \tag{A-7}$$

The Bowen ratio is related to the heat and moisture fluxes and is expressed in terms of the scaling temperature and humidity,

$$B = \frac{C_p T_*}{L_w Q_*} \tag{A-8}$$

where C_p is specific heat of air at constant pressure and L_w is latent heat of vaporization.

A.6 Scaling wind speed, U_*; temperature, T_*; and humidity, Q_*

The surface layer is characterized by fluxes of momentum, heat and moisture which are independent of height. These constant fluxes are used to define the scaling velocity, U_*; temperature, T_*; and humidity, Q_*;

$$U_* = \sqrt{-\overline{u'w'}} \qquad T_* = -\frac{1}{U_*}\overline{T'w'} \qquad Q_* = -\frac{1}{U_*}\overline{q'w'} \tag{A-9}$$

where U', T' and q' are fluctuations of horizontal wind, temperature and humidity about their means, and the overbar is an average among all fluctuations. These scaling variables are related to the vertical profiles of each variable,

$$U_* = kU[\ln(\frac{Z}{Z_o}) - \psi_M(z/L)]^{-1}$$

$$Q_* = \frac{k}{R}(q-q_s)[\ln(\frac{Z}{Z_{oQ}}) - \psi_Q(z/L)]^{-1} \qquad \text{(A-10)}$$

$$T_* = \frac{k}{R}(T-T_s)[\ln(\frac{Z}{Z_{oT}}) - \psi_H(z/L)]^{-1}$$

where U is the wind speed in m/s, T and T_s are the air and sea surface temperatures in °C, q and q_s are the specific humidities at the observation height Z and at the sea surface in grams per gram. Z_o, Z_{oT}, and Z_{oQ} are roughness parameters describing molecular transport of wind, temperature, and moisture near the surface, and ψ_M, ψ_H, and ψ_Q are empirical profile functions. The constant R is included in the equations for temperature and humidity. The value of this constant is accepted as 0.74 based on reliable field experiments.

A.7 Profile functions

The profile functions, ψ, were formulated by Businger et al. (1971). These functions have been verified both over land and over water and are given by,

$L \leq 0$ $\qquad\qquad$ $L > 0$

$$\psi_M = \ln\left[\left(\frac{1+x^2}{2}\right)\left(\frac{1+x}{2}\right)^2\right] - 2\arctan(x) + \pi/2 \qquad \psi_M = -\beta\frac{z}{L}$$

$$x = (1-\gamma_m\, z/L)^{1/4} \qquad \text{(A-11)}$$

$$\psi_H = \psi_Q = 2\ln\left[\frac{1+\sqrt{1-\gamma_H\frac{z}{L}}}{2}\right] \qquad \psi_H = \psi_Q = -\frac{\beta}{R}\frac{z}{L}$$

Constants in these formulations are determined by fitting the formulations to the data, and correspond best to one particular data set. Universal constants have so far not been found.

The hypothesis that the ψ are the same for heat and moisture is based mostly on measurements over land. There is considerable controversy whether the assumption is valid over the ocean; but no better hypotheses are available. Fortunately, in all equations, the ψ's are small compared to the logarithmic terms, so that extreme accuracy in the ψ's is not required. Further, ψ_Q occurs only in the correction of L for moisture, which itself is usually a small correction.

A.8 Roughness Lengths Z_o, Z_{oT}, Z_{oQ}

The molecular transport of momentum, heat and moisture near the surface is described by the values of Z_o, Z_{oT}, and Z_{oQ} respectively. In the marine environment, the roughness lengths have values on the order of 1 mm or less. The dependence of C_n^2 on Z_o is included primarily in the function $\ln\frac{Z}{Z_o}$, where Z is the elevation, taken to be 10 meters. Therefore C_n^2 should be insensitive to errors in Z_o. Separate treatments of Z_o, Z_{oT} and Z_{oQ} are necessary. The technique developed by Liu (1978) is used

here. Liu derived relations between U and U_* and the transfer coefficients for momentum, heat, and moisture, (C_D, C_H, C_Q). These relationships are shown in Figure A-1. The roughness lengths can be related to C_D, C_H, C_Q, and the profile functions by,

$$Z_o = Z \cdot \exp\left(\frac{k}{C_D^{1/2}} + \psi_M(z/L)\right)$$

$$Z_{oT} = Z \cdot \exp\left(\frac{k}{R} \frac{C_D^{1/2}}{C_H} + \psi_H(z/L)\right) \qquad \text{(A-12)}$$

$$Z_{oQ} = Z \cdot \exp\left(\frac{k}{R} \frac{C_D^{1/2}}{C_Q} + \psi_Q(z/L)\right).$$

The values of the roughness lengths cannot be obtained in closed form expressions, and the following procedure was used:

a. An arbitrary, initial value for L of 10^{30} was chosen. This implies that $Z/L \approx 0$, (since Z was assumed to be 10 m) and indicates neutral conditions.

b. The profile functions, ψ, were assigned their neutral values of zero.

c. The transfer coefficients C_Q and C_H were given initial values of 1.3×10^{-3} which is approximately the maximum value shown in Figure A-1.

d. The curve for C_D shown in Figure A-1 was approximated by the equation,

$$C_D = 10^{-3} \cdot (0.62375 + 0.8414 \cdot \mathrm{Log}_{10}(U)) \qquad \text{(A-13)}$$

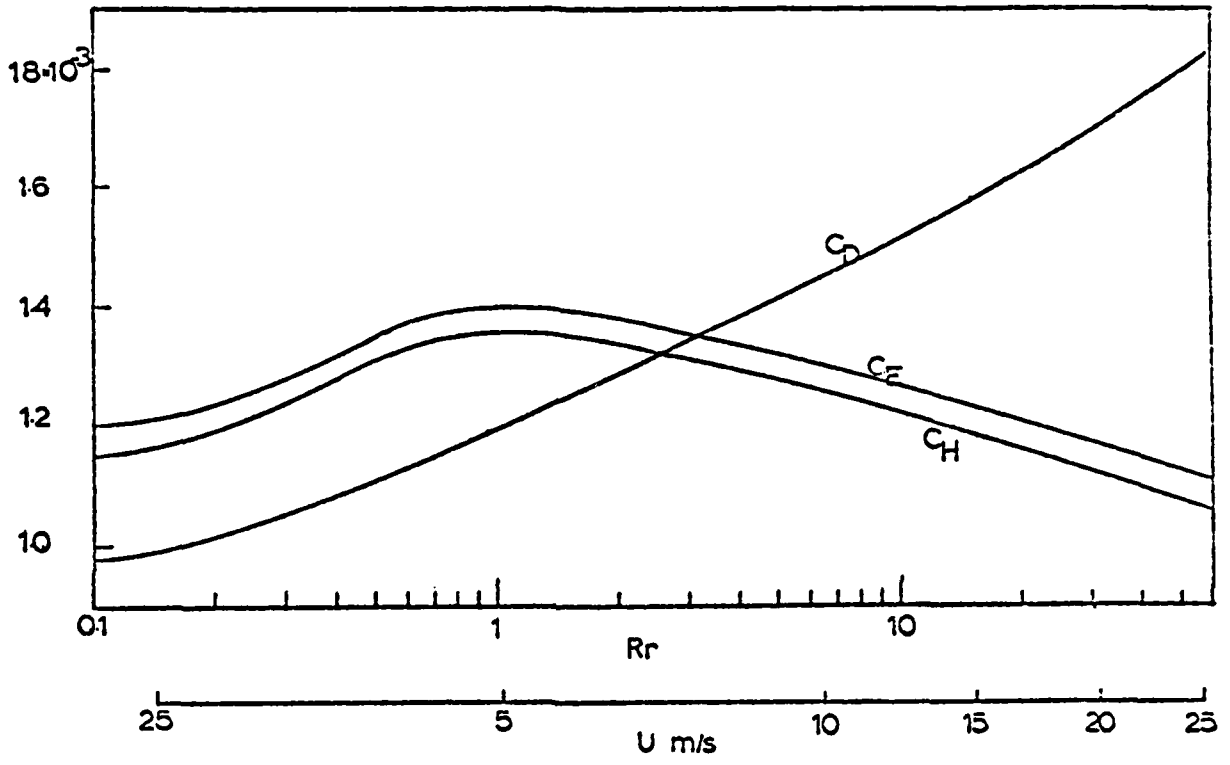

Fig. A-1. Bulk transfer coefficients at neutral conditions versus 10 m wind U and roughness Reynolds number R_r (Liu, 1978). The transfer coefficients are approximately calculated from wind U; when scaling speed U* and roughness length Z_o are found, transfer coefficients are found from R_r using formulas in the text.

where U is the wind speed. For this calculation only, reported values of U<2.5 m/s were changed to a minimum value of 2.5 m/s to correspond to the lower limit of the diagram. Using Eq. (A-13), an initial value of C_D was computed.

e. Z_o, Z_{oT} and Z_{oQ} were calculated from equation (A-12). A maximum value of 1 mm was allowed for all roughness lengths. Larger values were reduced to this limit.

f. The initial roughness lengths were used to calculate new values for the transfer coefficients, C_D, C_H and C_Q. These values in turn were used to compute the scaling parameters U_*, T_* and Q_*. At this point the roughness Reynolds number was found by,

$$R_r = \frac{Z_o U_*}{\nu} \qquad \text{(A-14)}$$

where ν is the kinematic viscosity of air. As shown in Figure A-1, a minimum value of 0.1 was allowed for R_r.

g. A new set of roughness lengths was calculated using another approximation to the curve for C_D in Figure A-1 and the arbitrary values of C_H = .0011 and C_Q = .0012. The equation for C_D is

$$C_D = 10^{-3} \cdot (1.233 + 0.336 \cdot \mathrm{Log}_{10}(R_r)) \cdot \qquad \text{(A-15)}$$

A minimum value of 0.75×10^{-3} was allowed. This corresponds to the lower limit in Figure A-1.

A.9 Sea Surface Temperature, T_s

In most cases, bucket temperature, T_w, rather than the surface temperature is measured. T_s was estimated from a theory by Liu (1978). Liu, (Figure A-2) gives $T_s - T_w$ as a function of the wind speed and the difference between bucket temperature and air temperature at 10 m height, ΔT.

Liu's diagram was approximated by the following equations:

$$T_w - T_s = .025\Delta T + 0.1 \quad (U>6 \text{ m sec}^{-1}) \tag{A-16}$$

$$T_w - T_s = 0.1\Delta T + .8 - U(.117 + .0125\Delta T) (U \leq 6 \text{ m sec}^{-1})$$

where the temperature is in °C and the wind speed is in m sec^{-1}.

A.10 Evaluation of constants

Certain empirical constants were introduced in the definition of scaled quantities, the vertical flux profiles, and in the C_T^2 stability function. These constants depend on the particular data set from which they were determined, and there is no uniform agreement in the literature on the best values of each. In choosing the constants, a set of values corresponding to one particular data set should be chosen because the constants are interdependent. Table 1 provides the values of the constants used in this analysis.

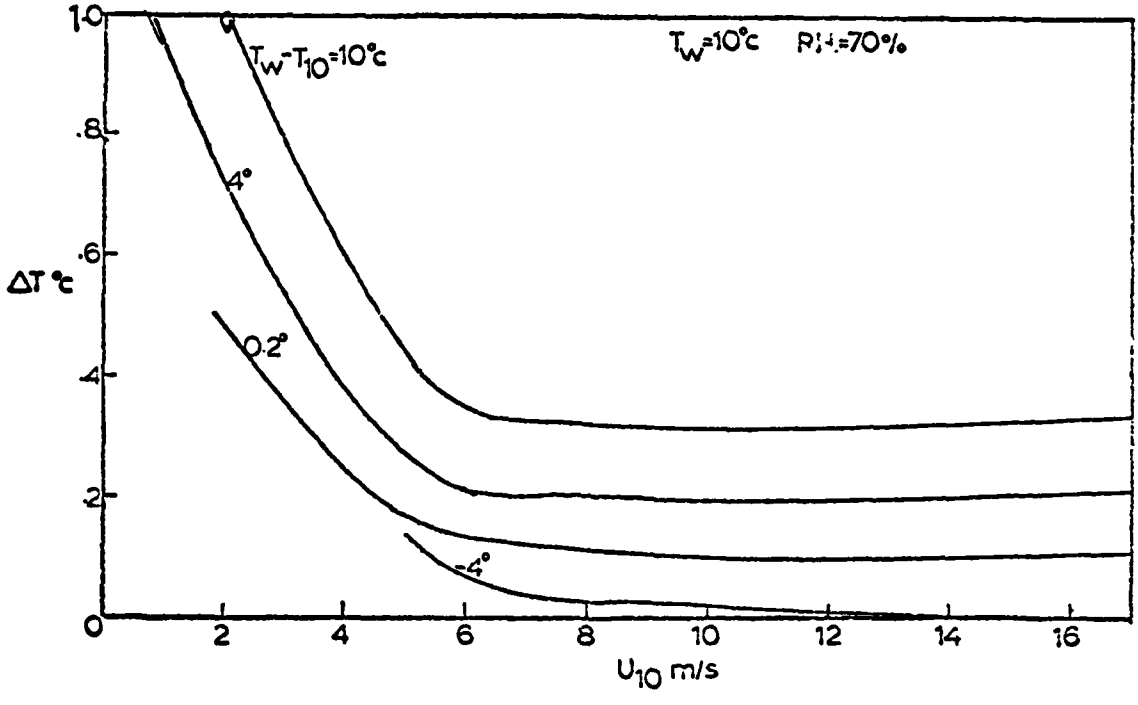

Fig. A-2. Temperature difference across the aqueous sublayer versus 10 m wind for values of air-bulk water temperature difference T_w-T_{10} (Liu, 1978). These formulas account for radiation and molecular effects in the surface layer.

Table 1

Constant	Value Used
For Scaling Functions	
k	0.35
R	.74
For Profile Functions	
γ_m	15
γ_H	6
β	4.7
For Stability Function	
b	.667

A.11 Calculation of C_n^2

The step-by-step procedure used to calculate C_n^2 is given below.

a. Modify the sea surface temperature measurement to an actual sea surface temperature value using Eq. (A-16) and T_s, T_w and U.

b. Set initial stability to neutral, i.e., $L=10^{30}$, $Z/L\approx 0$, and $\psi_M = \psi_H = \psi_Q = 0$.

c. The bulk wind speed determines an initial value of C_D using Eq. (A-13). Initial values for C_H and C_Q are set to .0013.

d. Calculate Z_o, Z_{oT}, and Z_{oQ} from C_D, C_H, C_Q with Eq. (A-12).

e. Calculate new values for C_D, C_H, and C_Q by rearranging Eq. (A-12).

f. Evaluate scaling parameters U_*, T_* and Q_* using Eq. (A-10).

g. Evaluate Bowen ratio, B, using Eq. (A-8).

h. Evaluate Monin-Obukhov length for moist atmosphere using Eqs. (A-6) and (A-7).

i. Test if the new L is within 0.1% of the last value of L. If so, go to statement m. If not, go to statement j.

j. Calculate stability functions ψ_M, ψ_H, ψ_Q using Eq. (A-11).

k. Calculate roughness Reynolds number R_r from Eq. (A-14).

l. Evaluate C_D from Eq. (A-15) using R_r and set C_H and C_Q to .0011 and .0012 respectively. Go to statement d.

m. Evaluate C_T^2 stability function, g(z/L), using Eq. (A-5).

n. Evaluate C_T^2 using Eq. (A-4).

o. Calculate C_n^2 using Eq. (A-3).

This procedure is graphically outlined in Figure A-3.

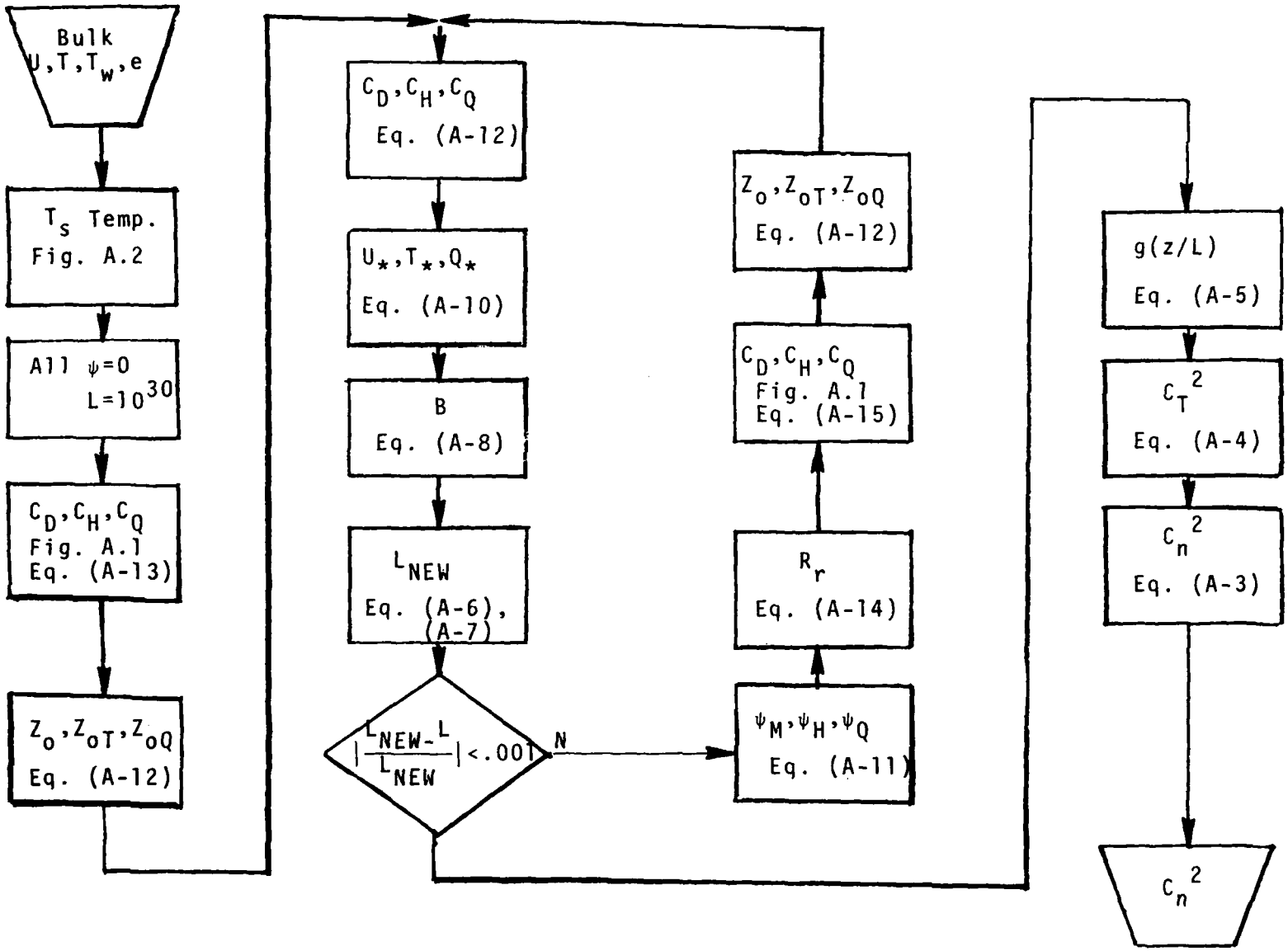

Figure A-3. Flow chart of surface layer C_n^2 calculation. Symbols, equation numbers, and figure numbers are those used in text.

Glossary and Values for C_n^2 Turbulence Model

B	-	Bowen ratio
C_D, C_H, C_Q	-	bulk transfer coefficients
C_e	-	moisture structure function parameter
C_{eT}	-	temperature/moisture correlation parameter
C_n^2	-	index of refraction structure function parameter
C_p	-	specific heat of air at constant pressure (0.24 cal/g K)
C_T^2	-	temperature structure function parameter
g	-	acceleration of gravity (9.8 m/s^2)
K	-	von Kármán constant (.35)
L	-	Monin-Obukov length (m)
L_w	-	latent heat of vaporization (591.7 cal/g)
n	-	optical index of refraction
P	-	atmospheric pressure (mb)
q	-	specific humidity (g per g)
Q_*	-	scaling humidity (g per g)
R	-	scaling constant (.74)
R_r	-	roughness Reynolds number
T	-	temperature (K or °C)
T_s	-	sea surface temperature (°C)
T_w	-	bucket temperature (°C)
T_*	-	scaling temperature (K)
U	-	wind speed (m/sec)
U_*	-	scaling velocity (m/sec)
Z,z	-	observation height (assumed 10 m)
Z_o	-	roughness lengths (m)
β	-	profile function constant (4.7)
γ_H	-	heat flux profile parameter (6.0)
γ_m	-	momentum flux profile parameter (15.0)
ν	-	kinematic viscosity of air (1.35×10^{-5} m^2/s)
ψ	-	profile functions

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FIGURES

Figures showing isopleths of mean C_n^2 values and of standard deviations are sequenced numerically for the twelve months of the calendar year as follows:

Means

Day and Night -- Figs. 1-12 ("All Times")
Daytime Only -- Figs. 13-24
Nighttime Only - Figs. 25-36

Standard Deviations

Day and Night -- Figs. 37-48 ("All Times")
Daytime Only -- Figs. 49-60
Nighttime Only - Figs. 61-72

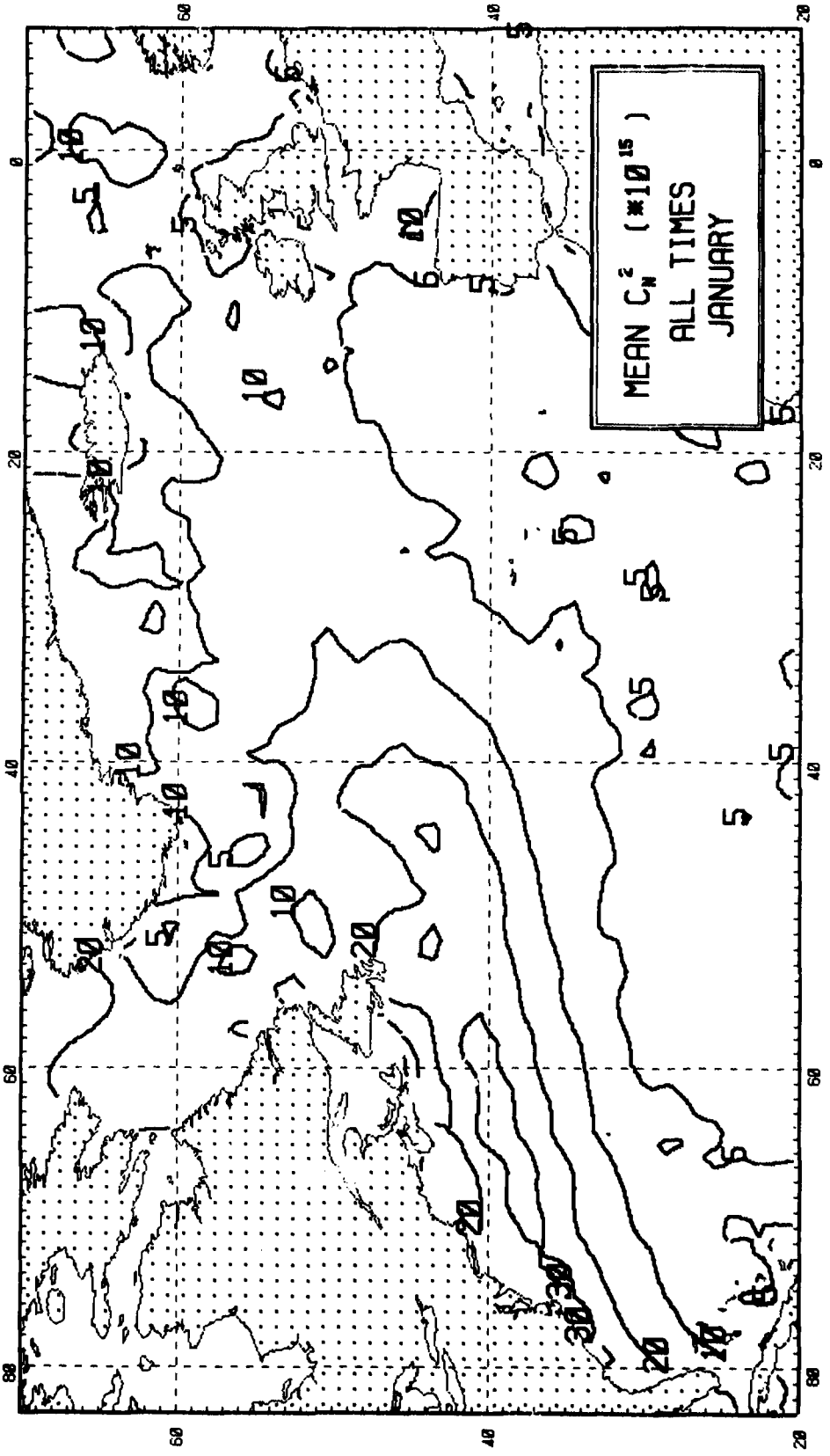


FIGURE 1

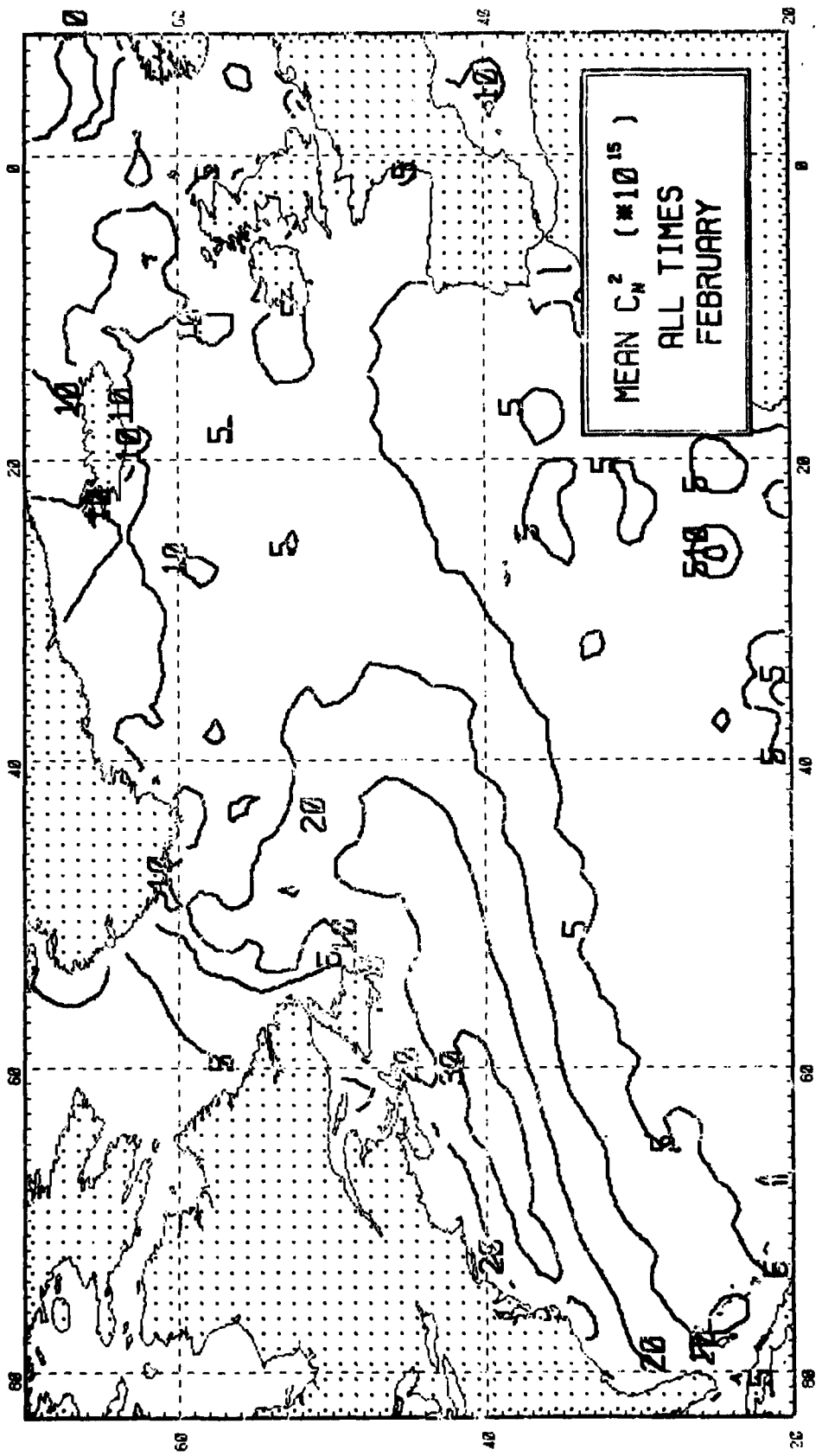


FIGURE 2

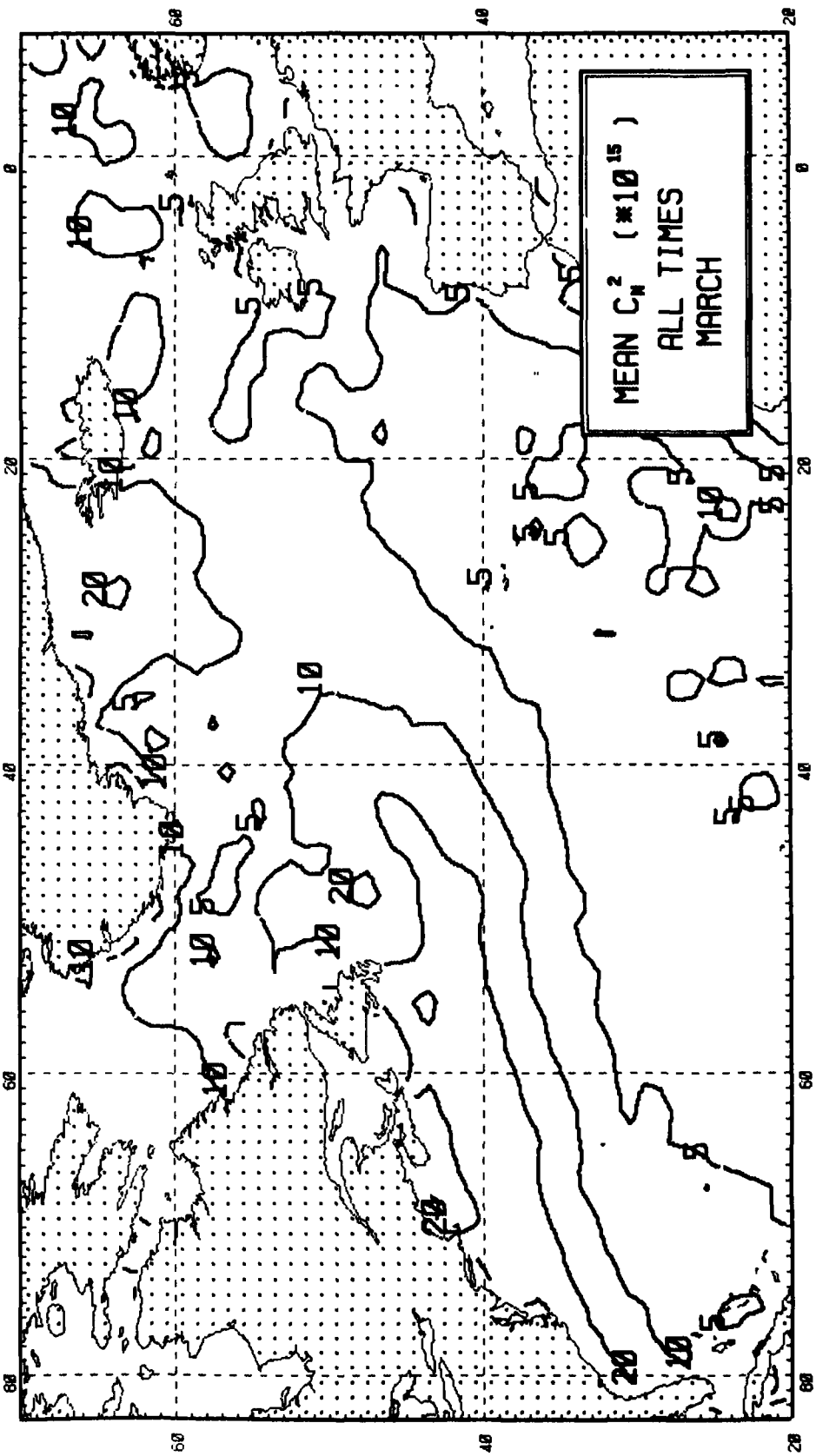


FIGURE 3

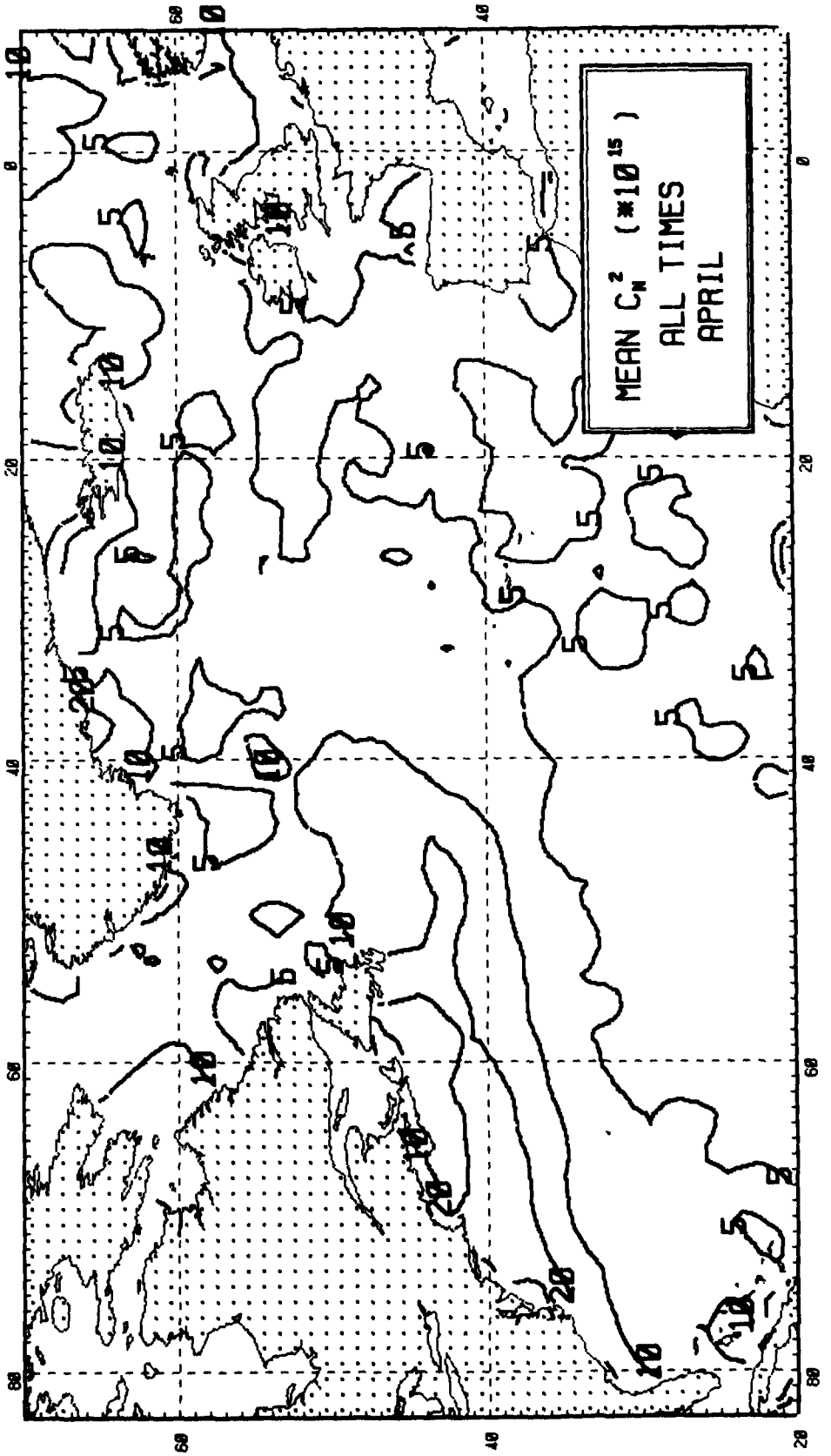


FIGURE 4

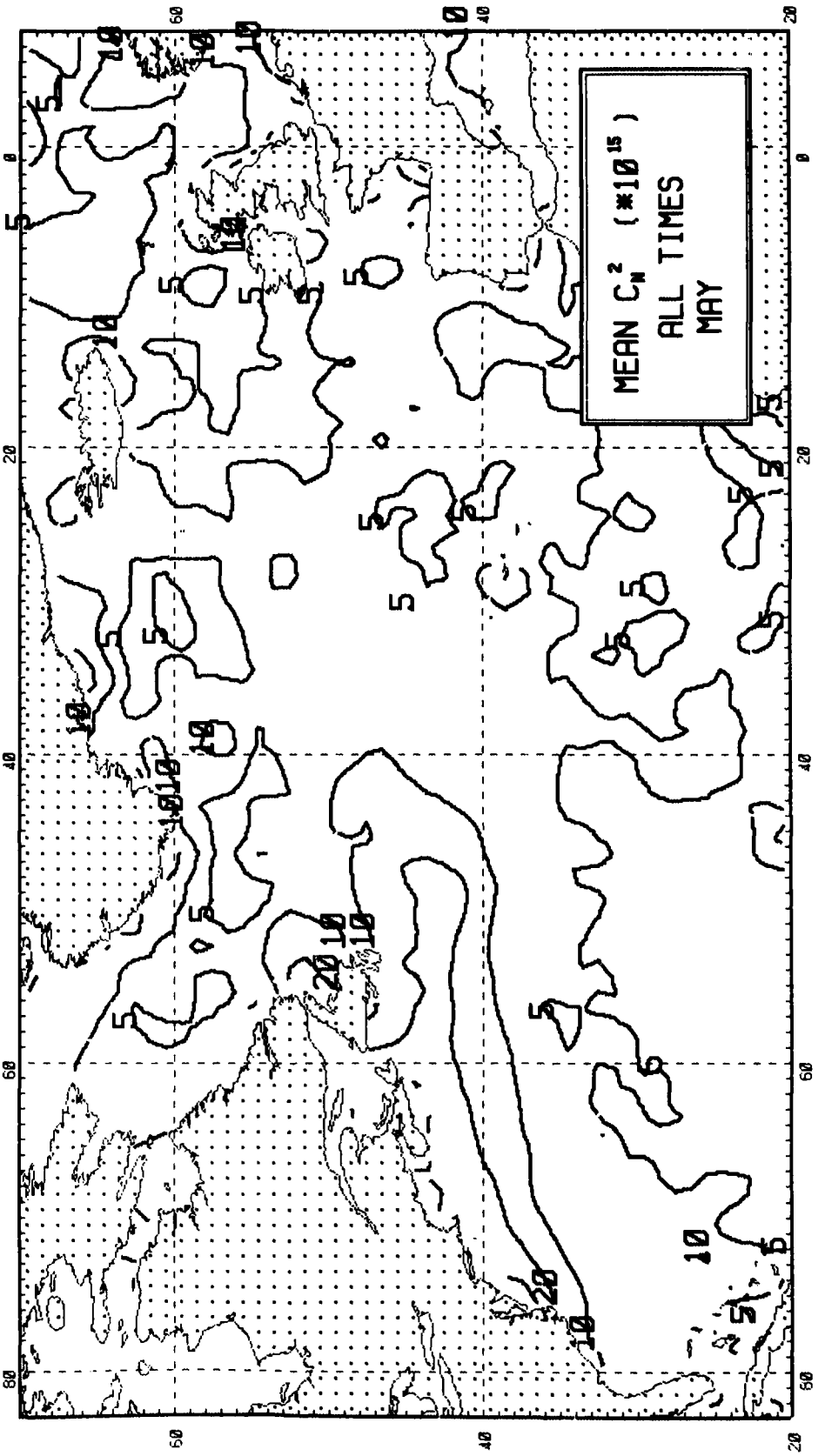


FIGURE 5

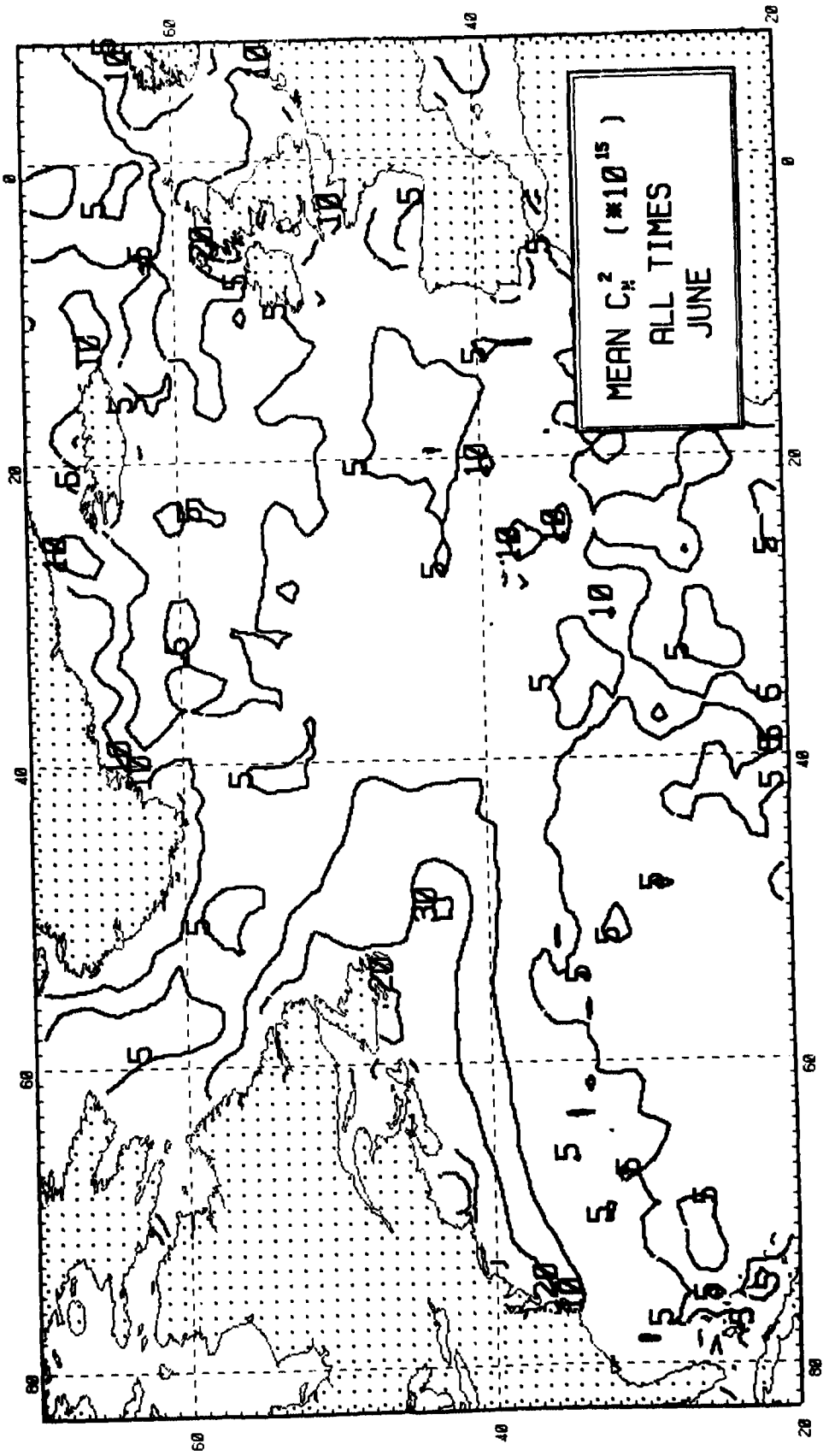


FIGURE 6

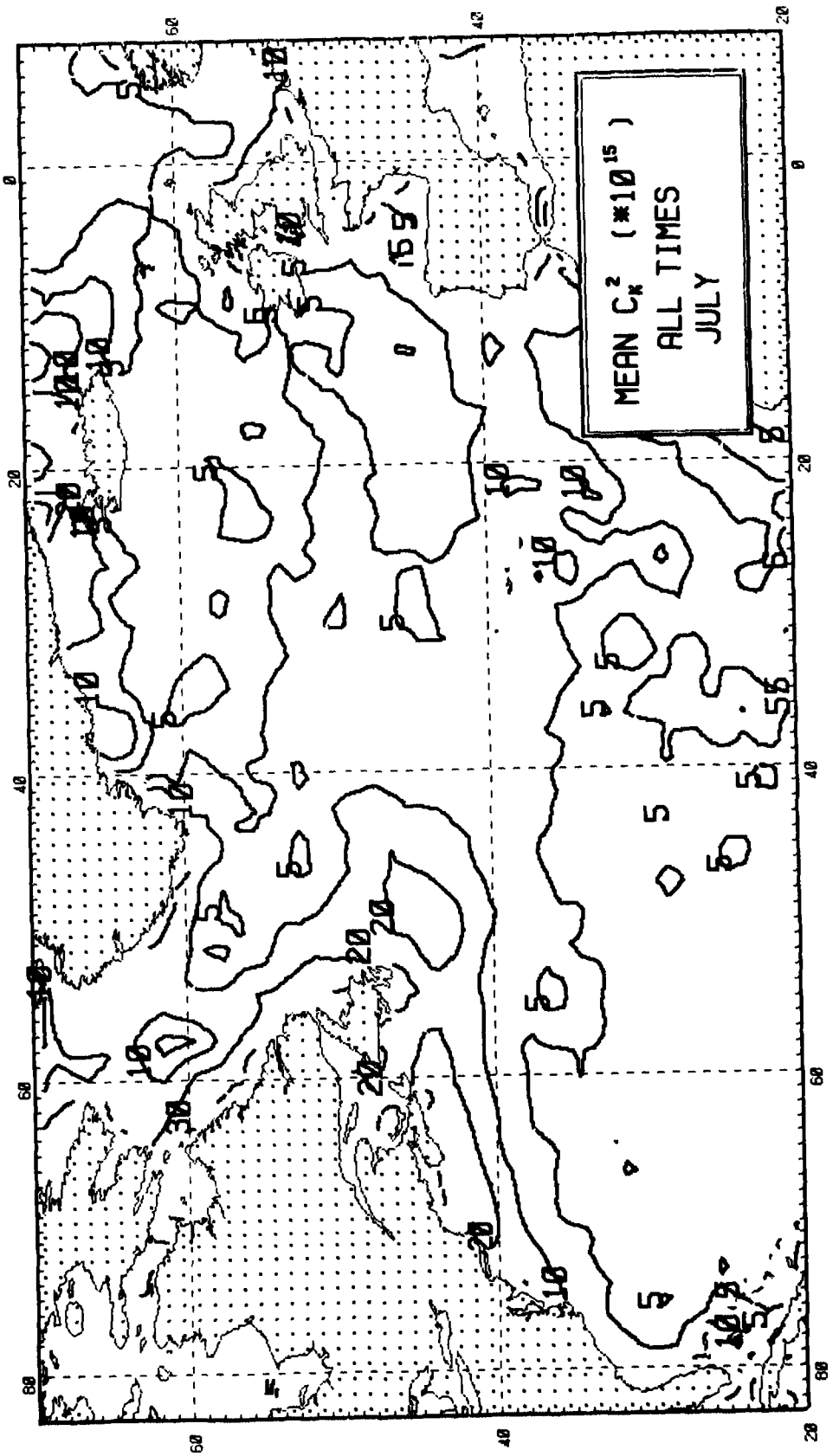


FIGURE 7

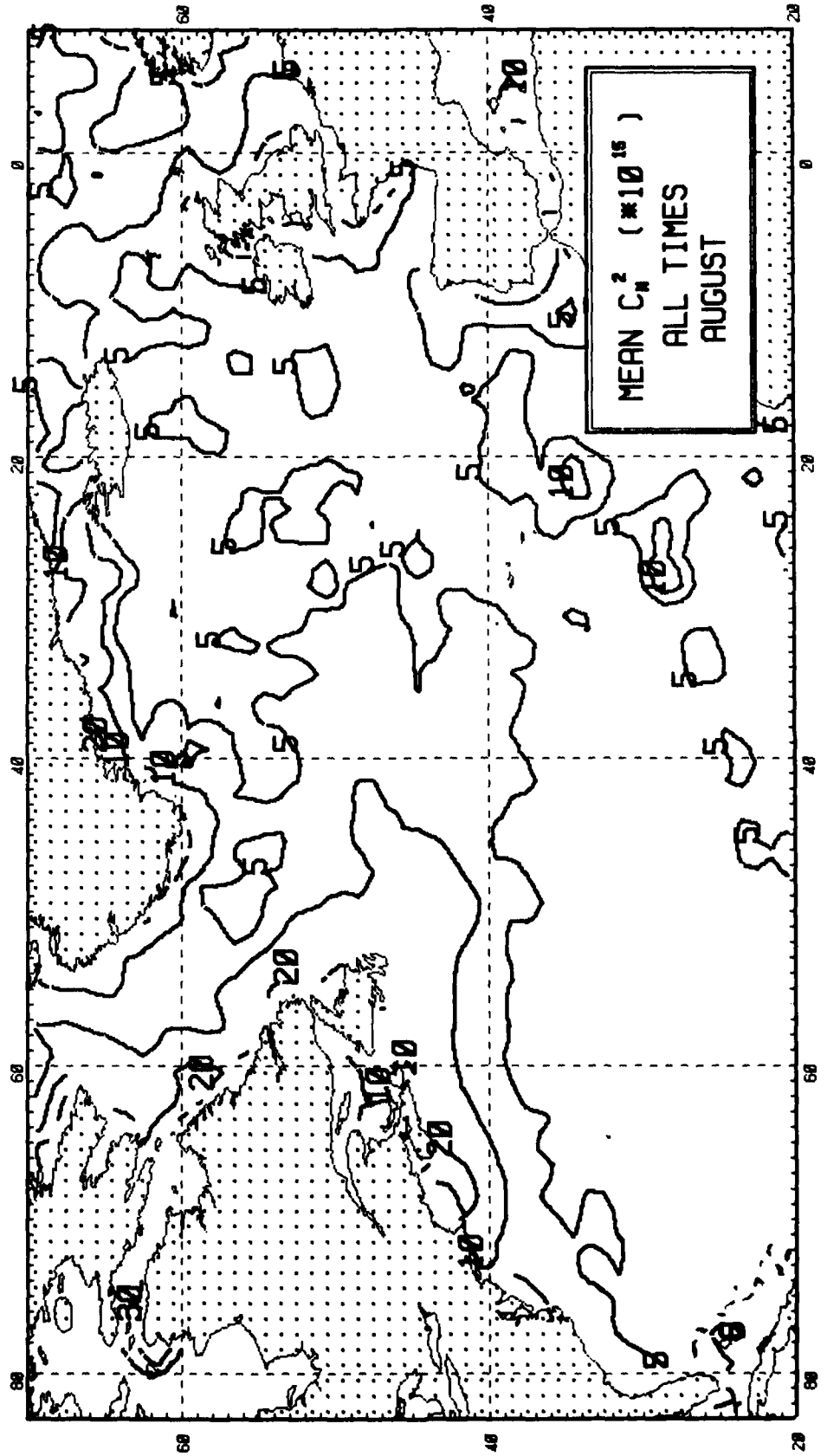


FIGURE 8

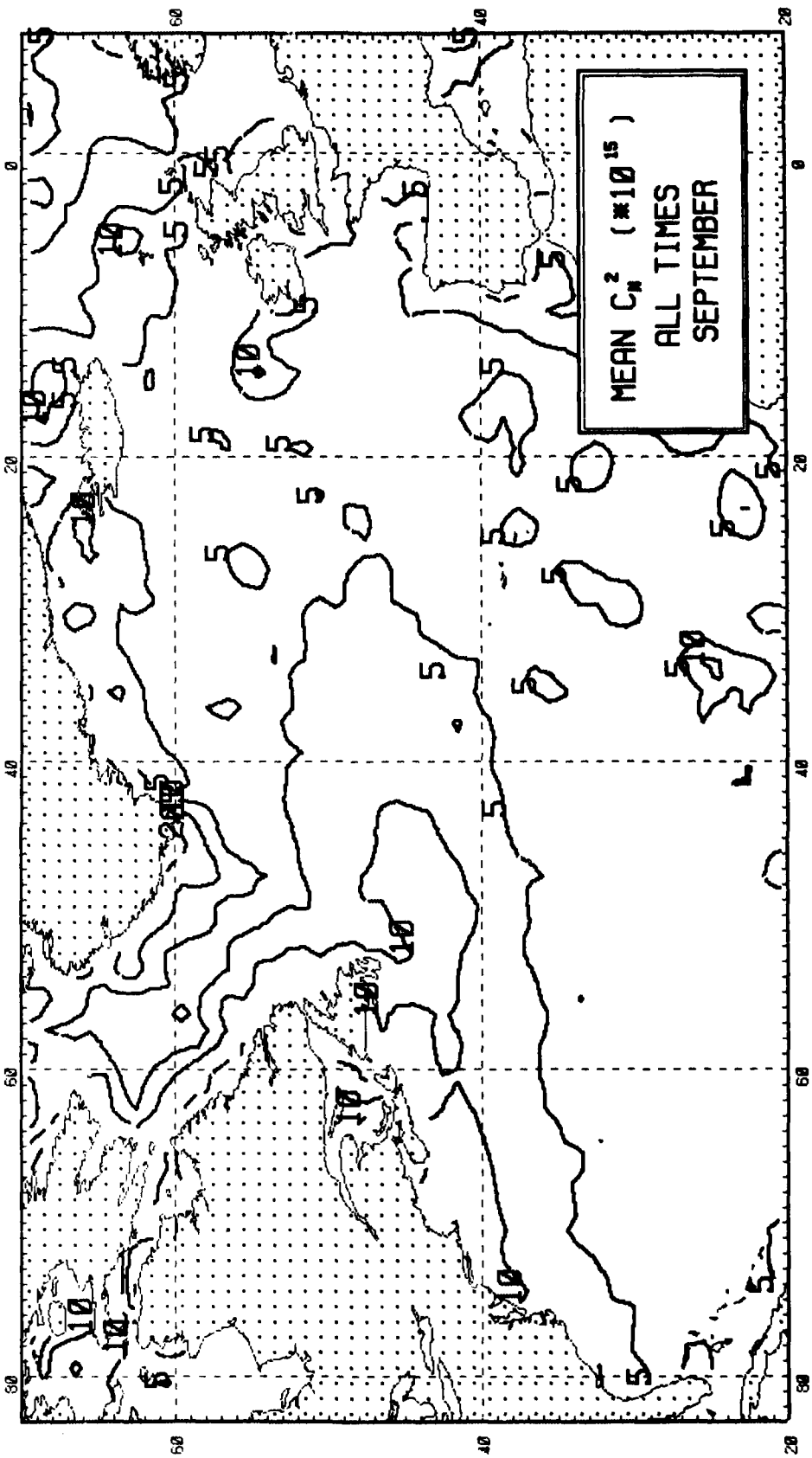


FIGURE 9

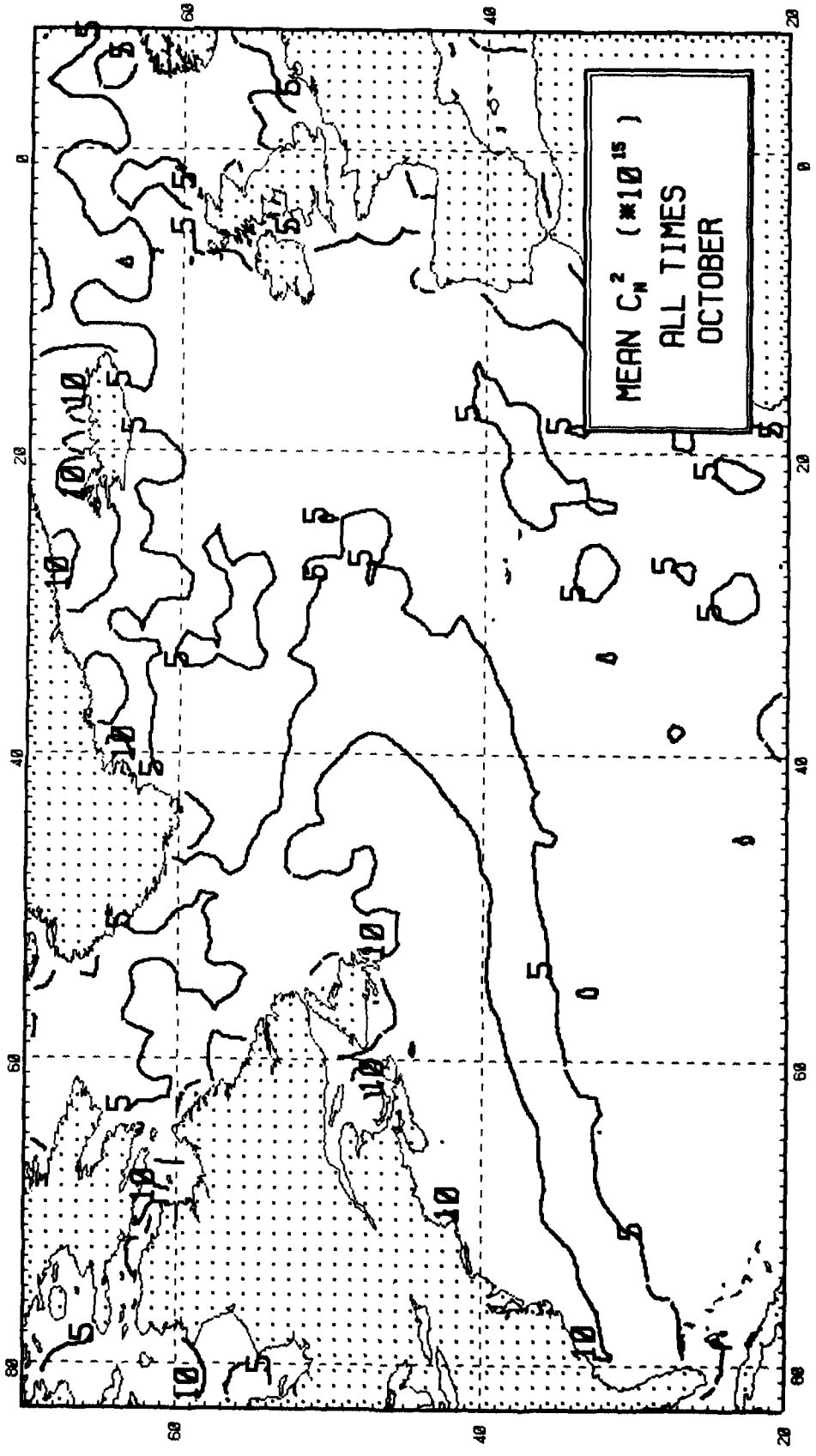


FIGURE 10

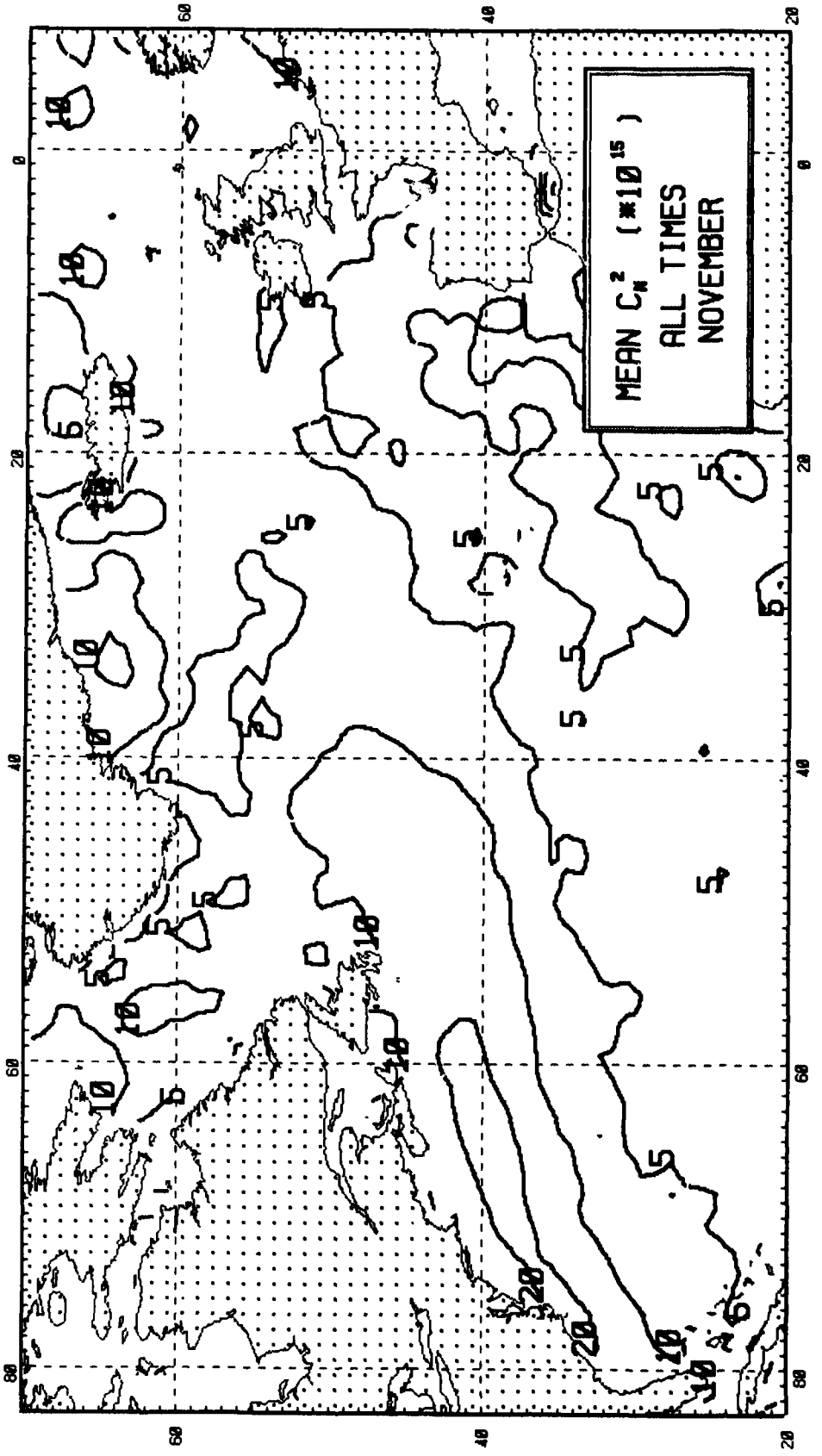
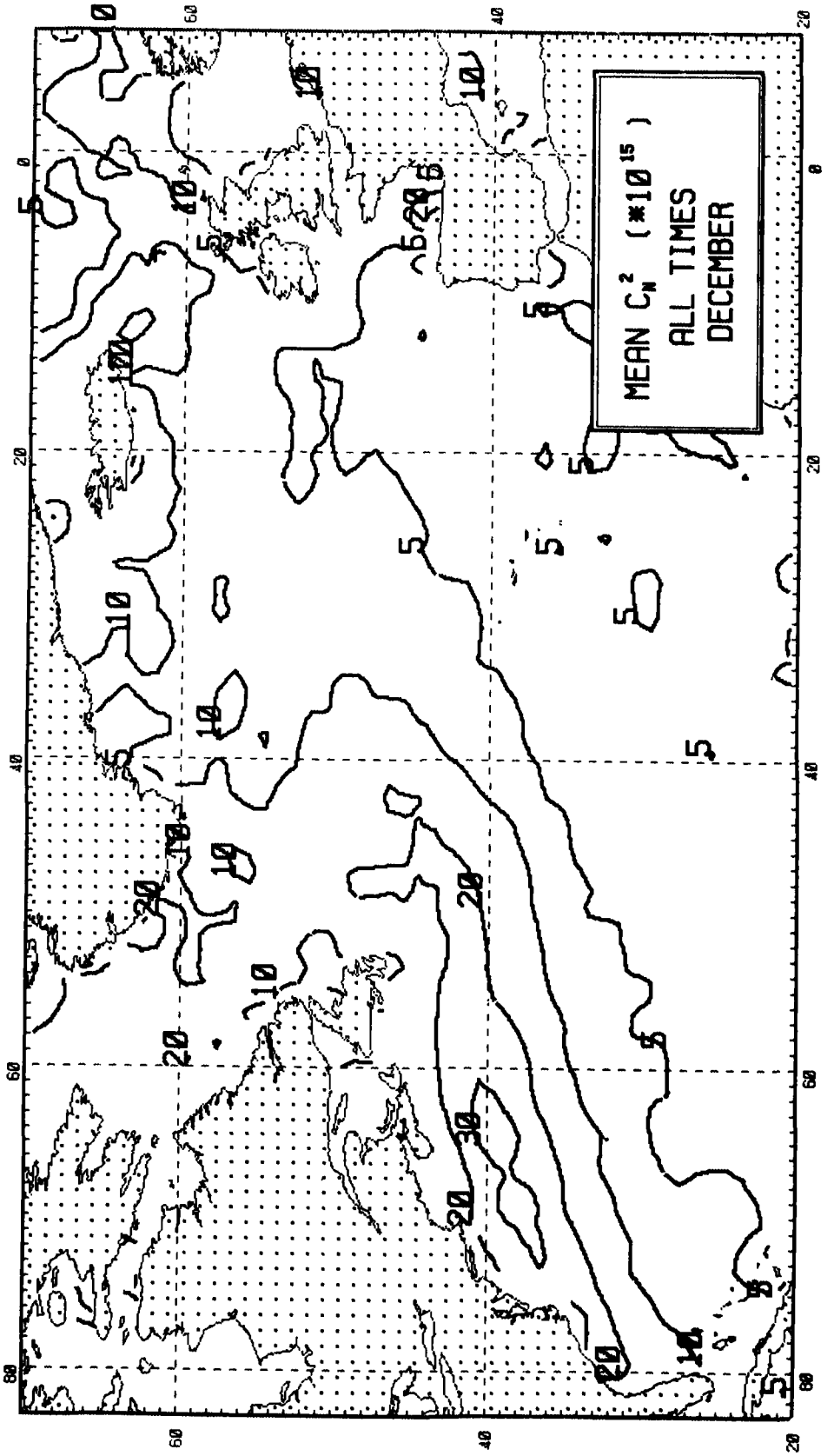


FIGURE 11



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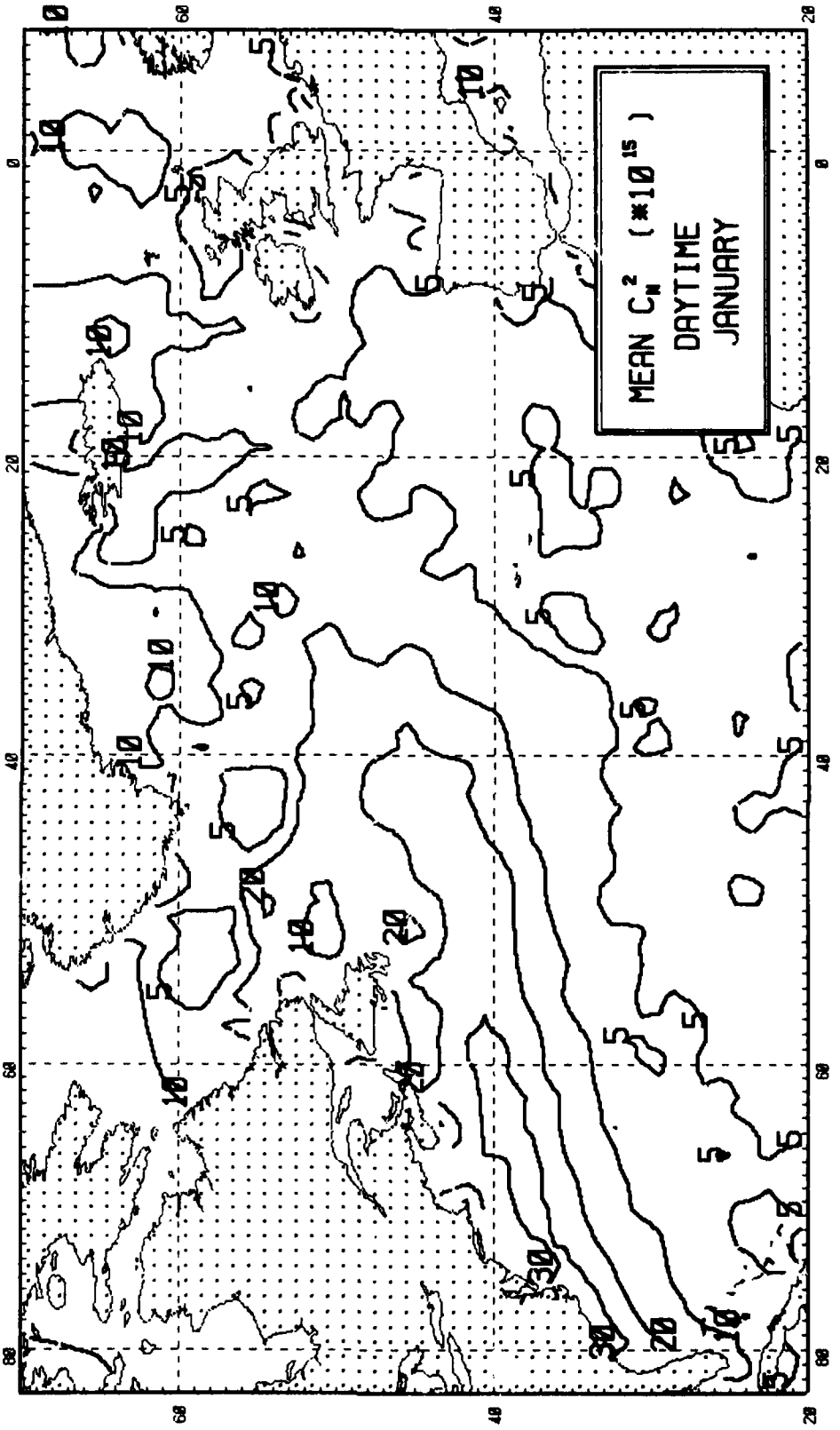


FIGURE 13

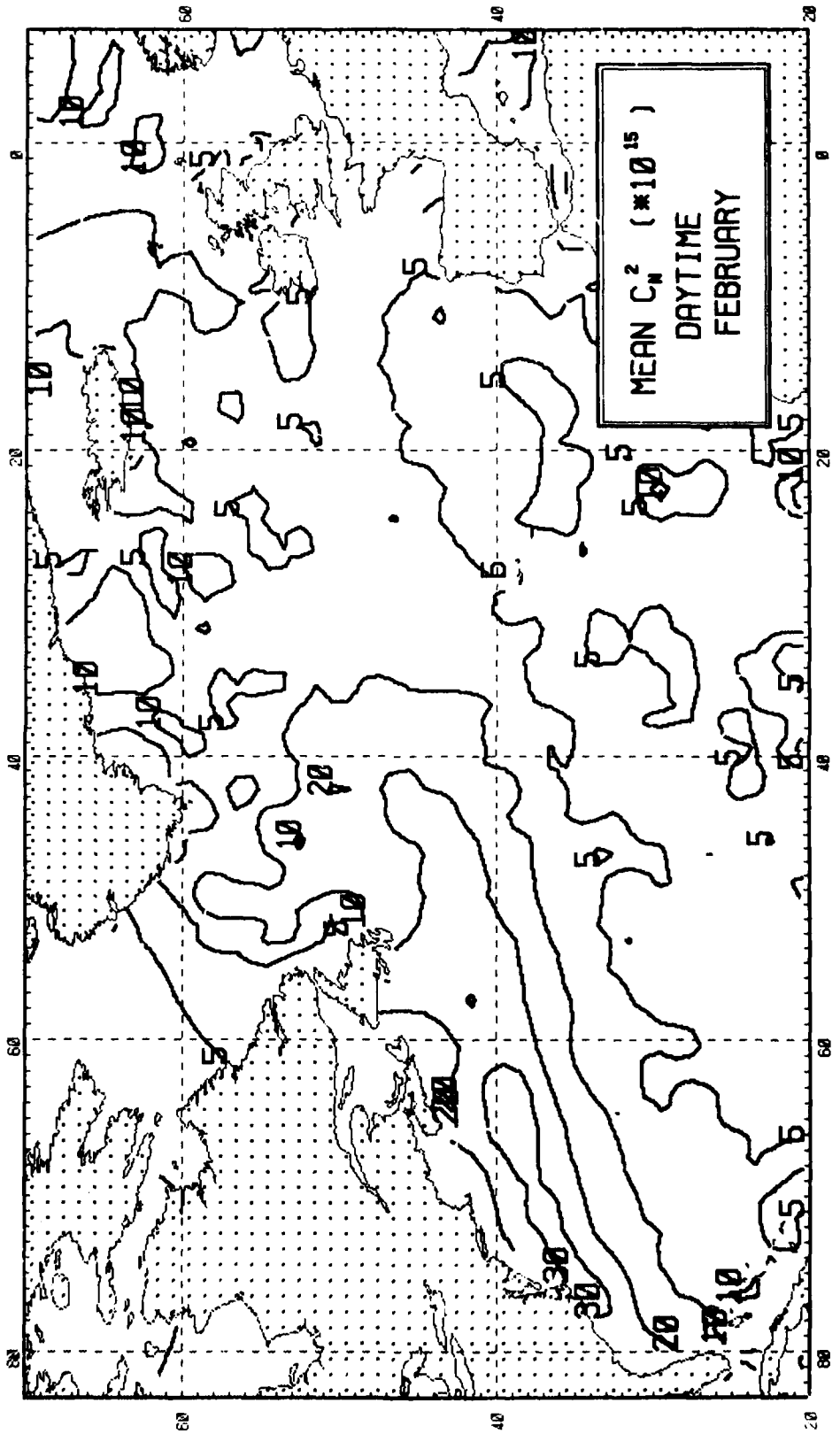


FIGURE 14

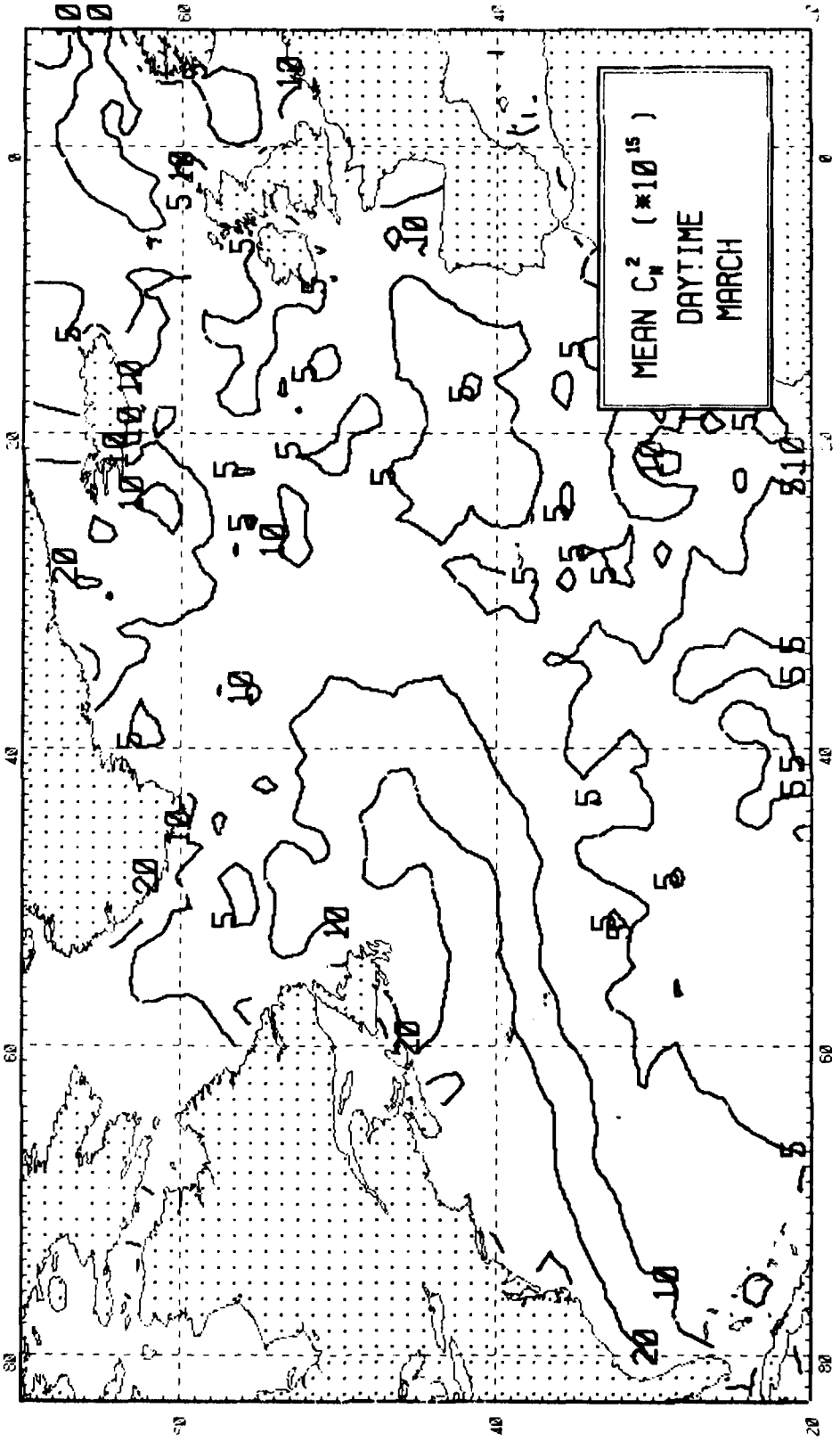


FIGURE 15

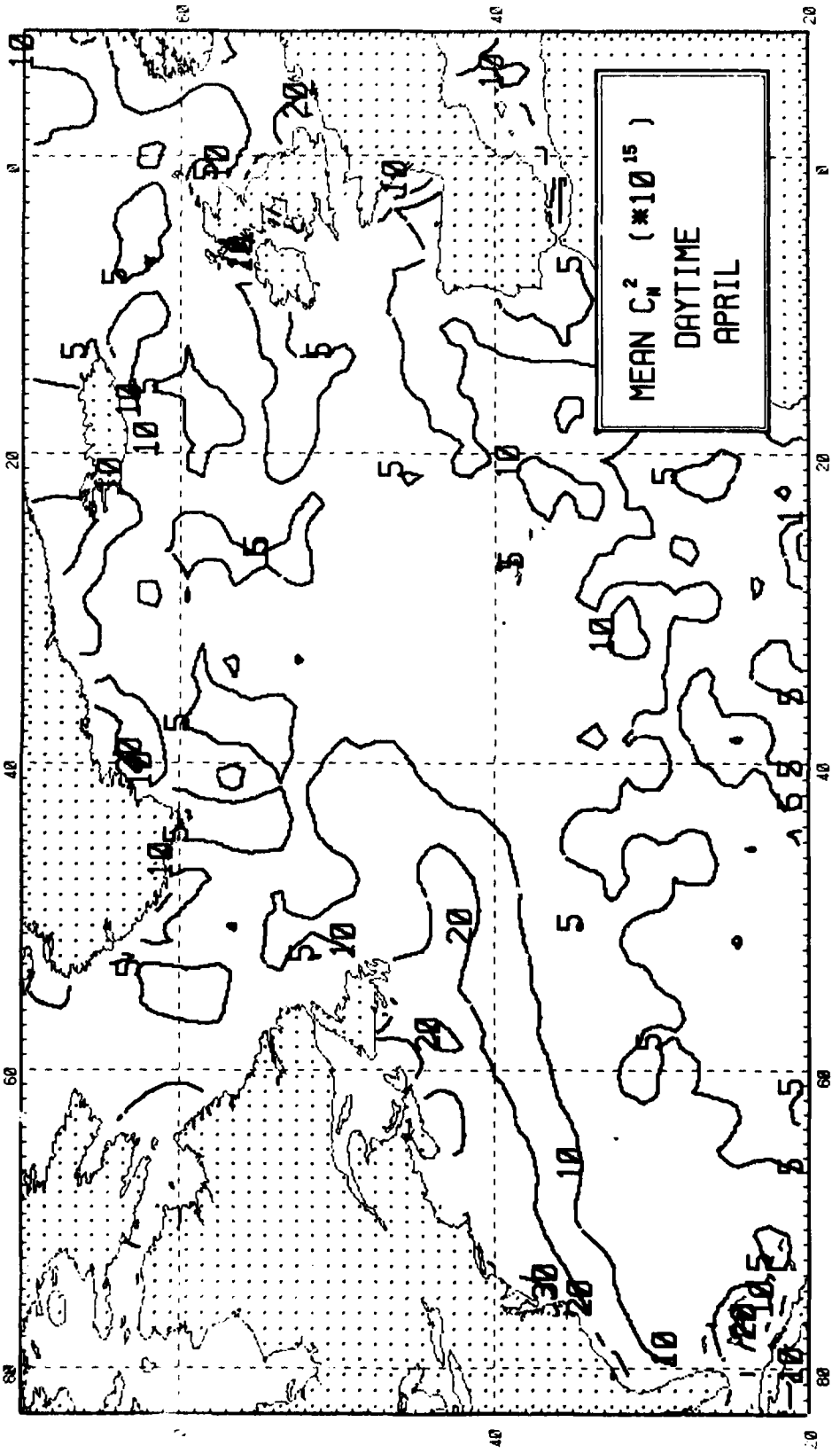


FIGURE 16

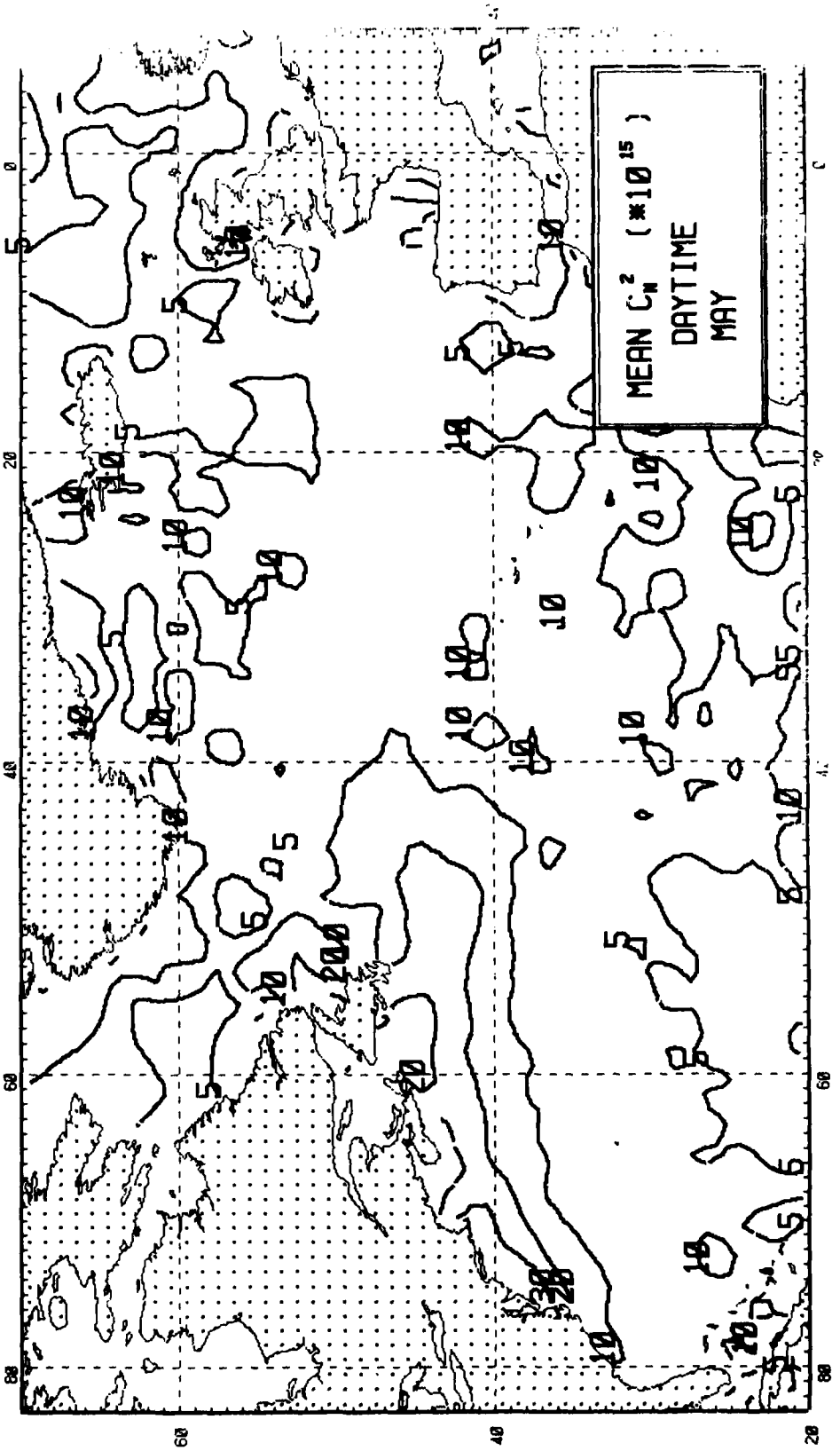
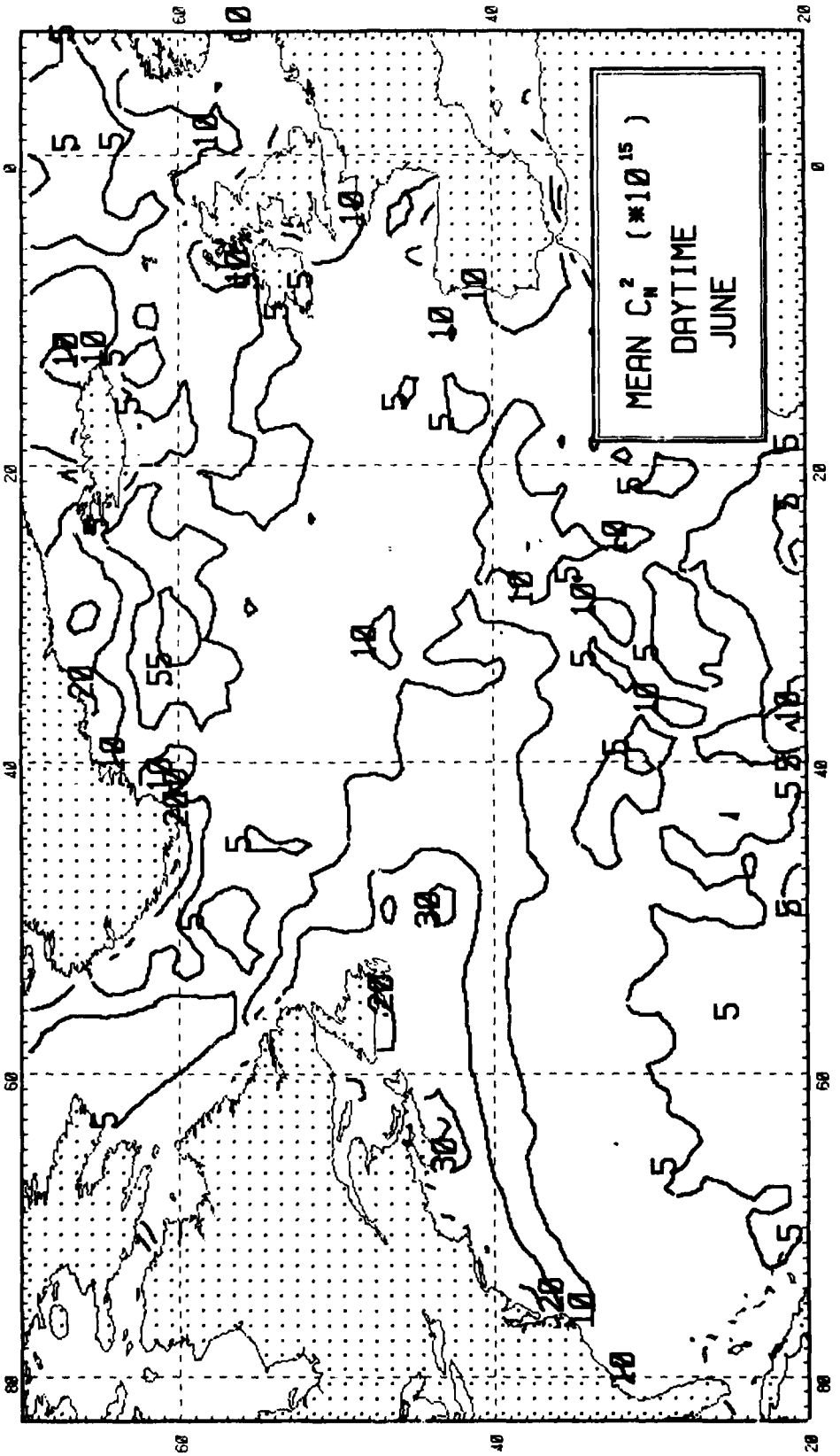


FIGURE 17



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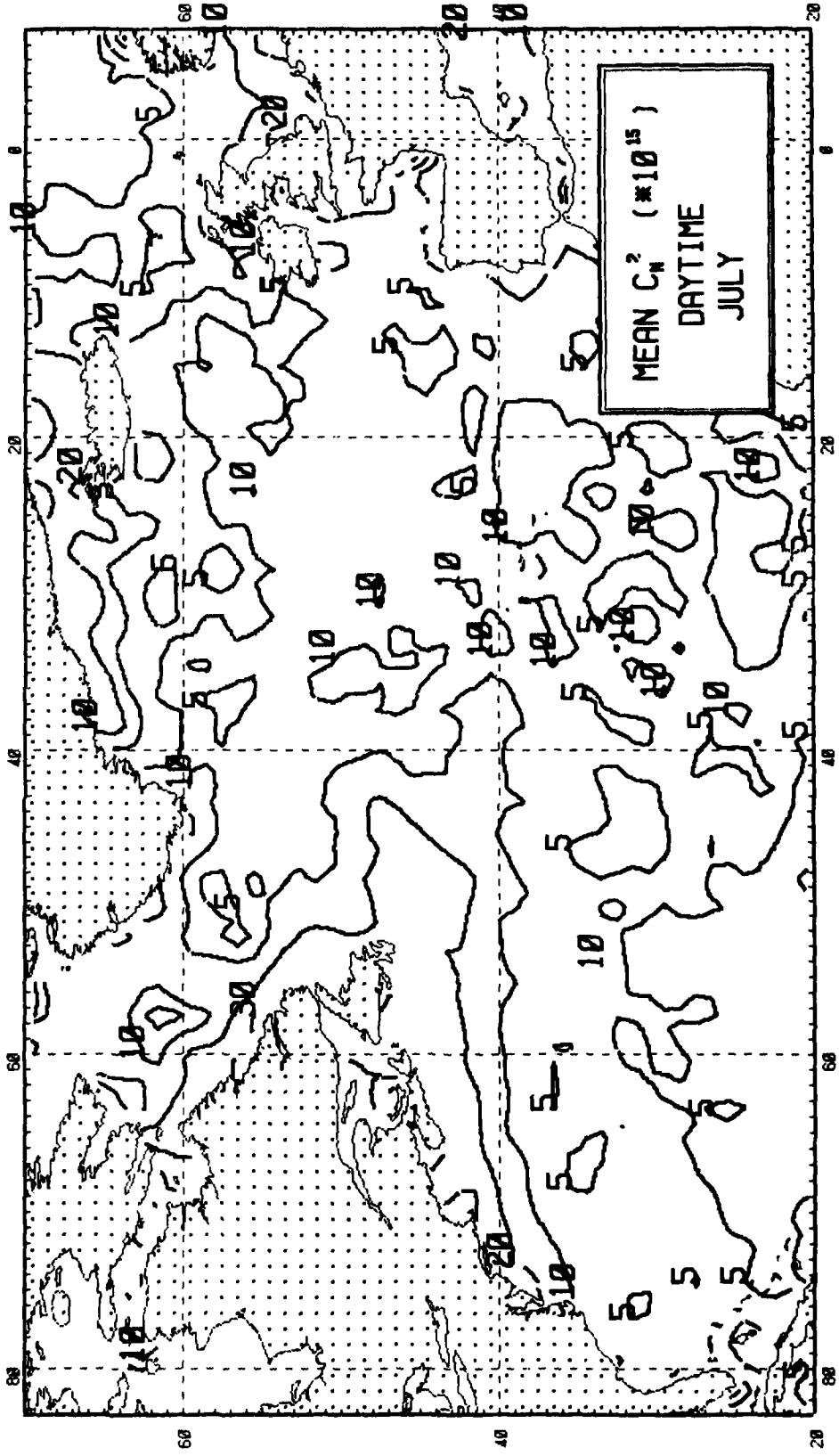

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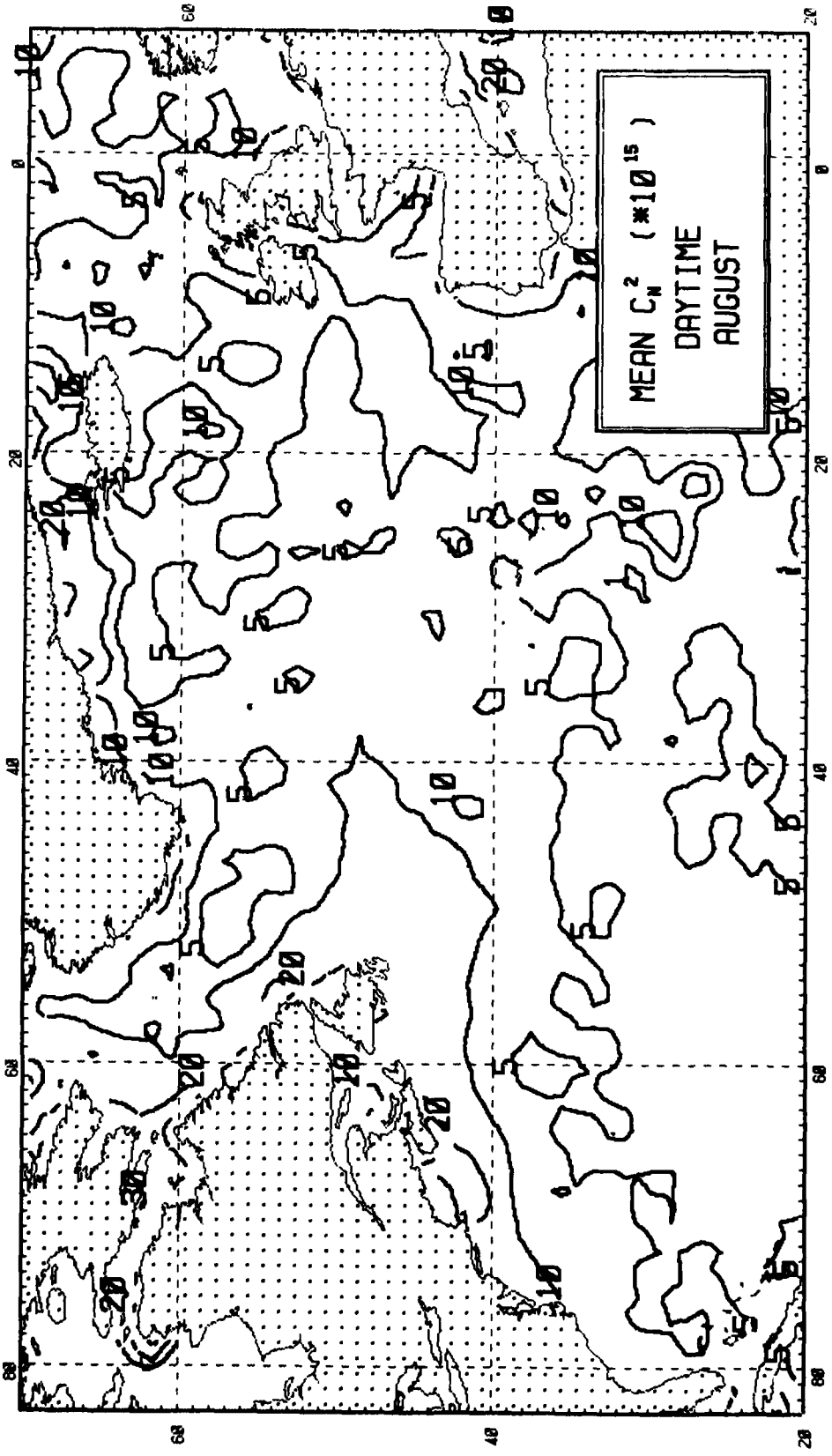


FIGURE 20

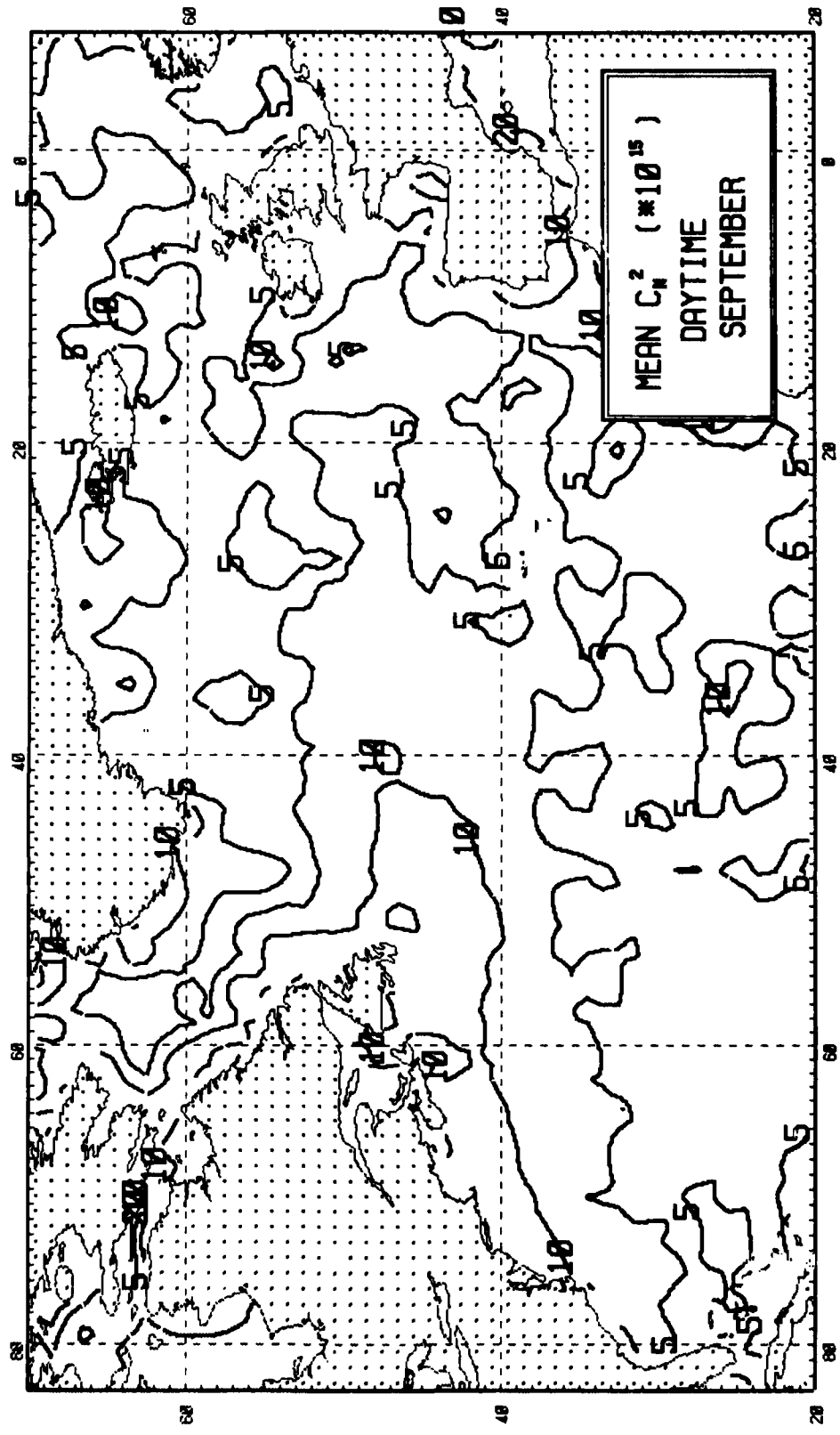


FIGURE 21

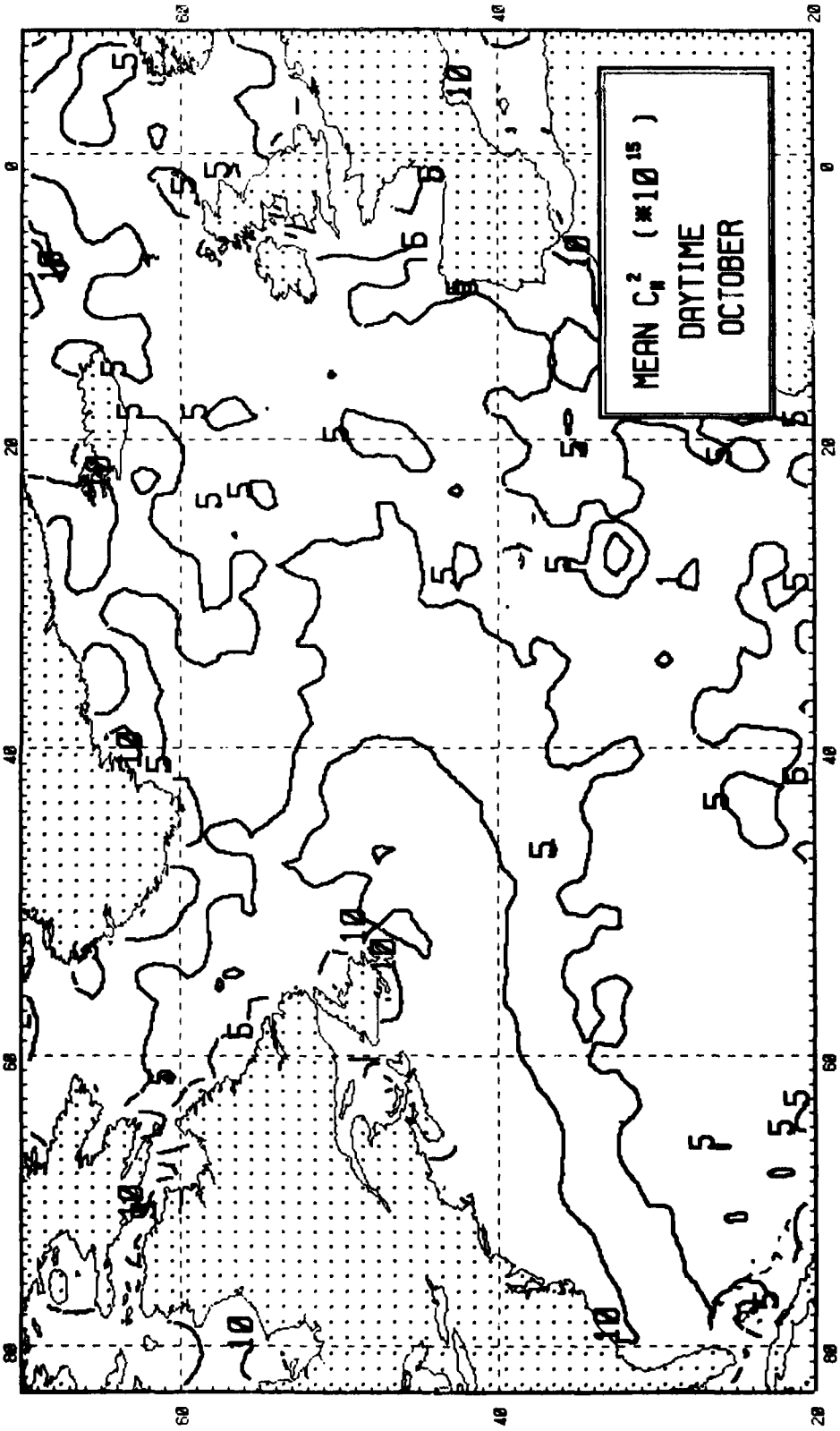


FIGURE 22

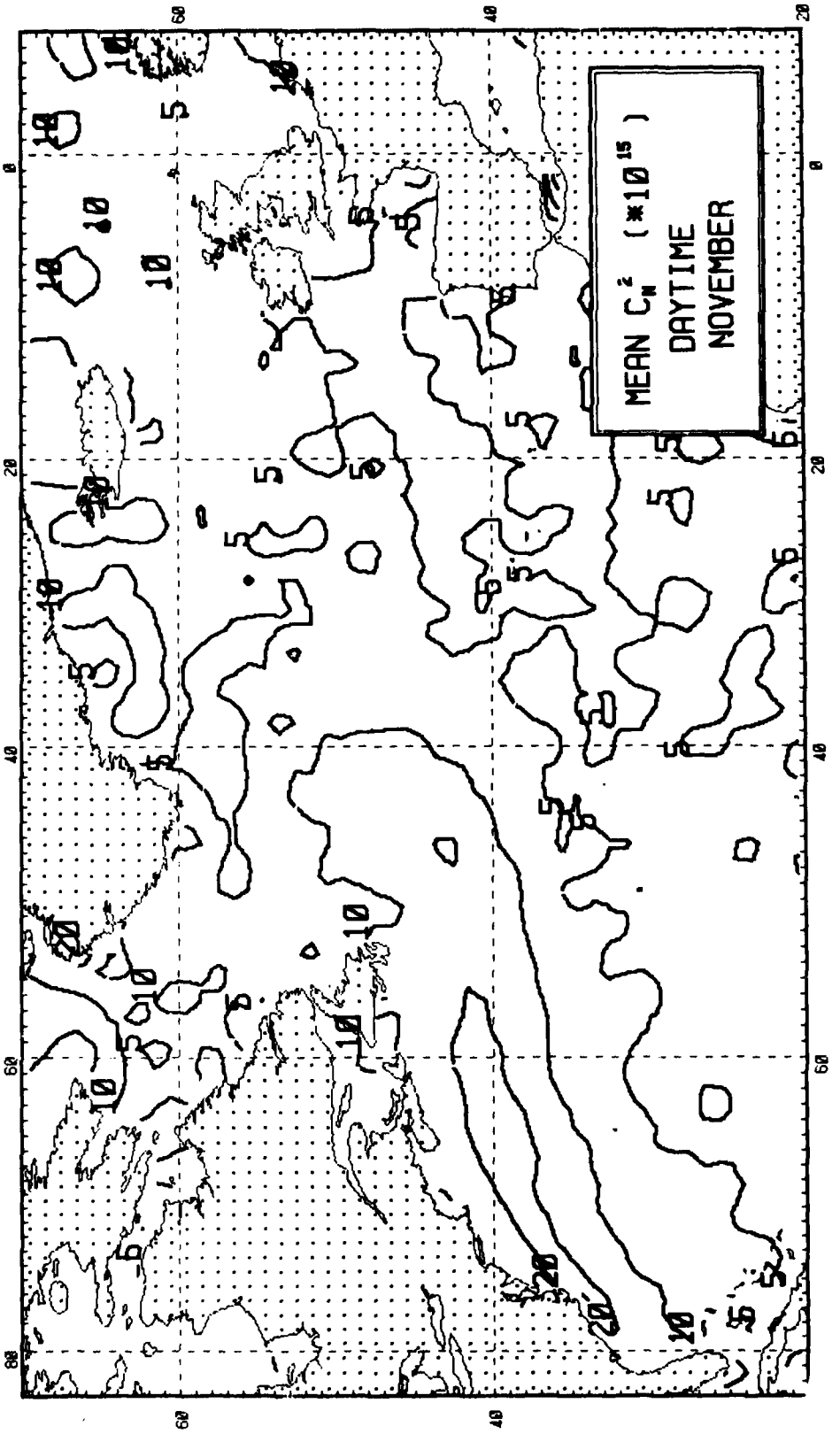
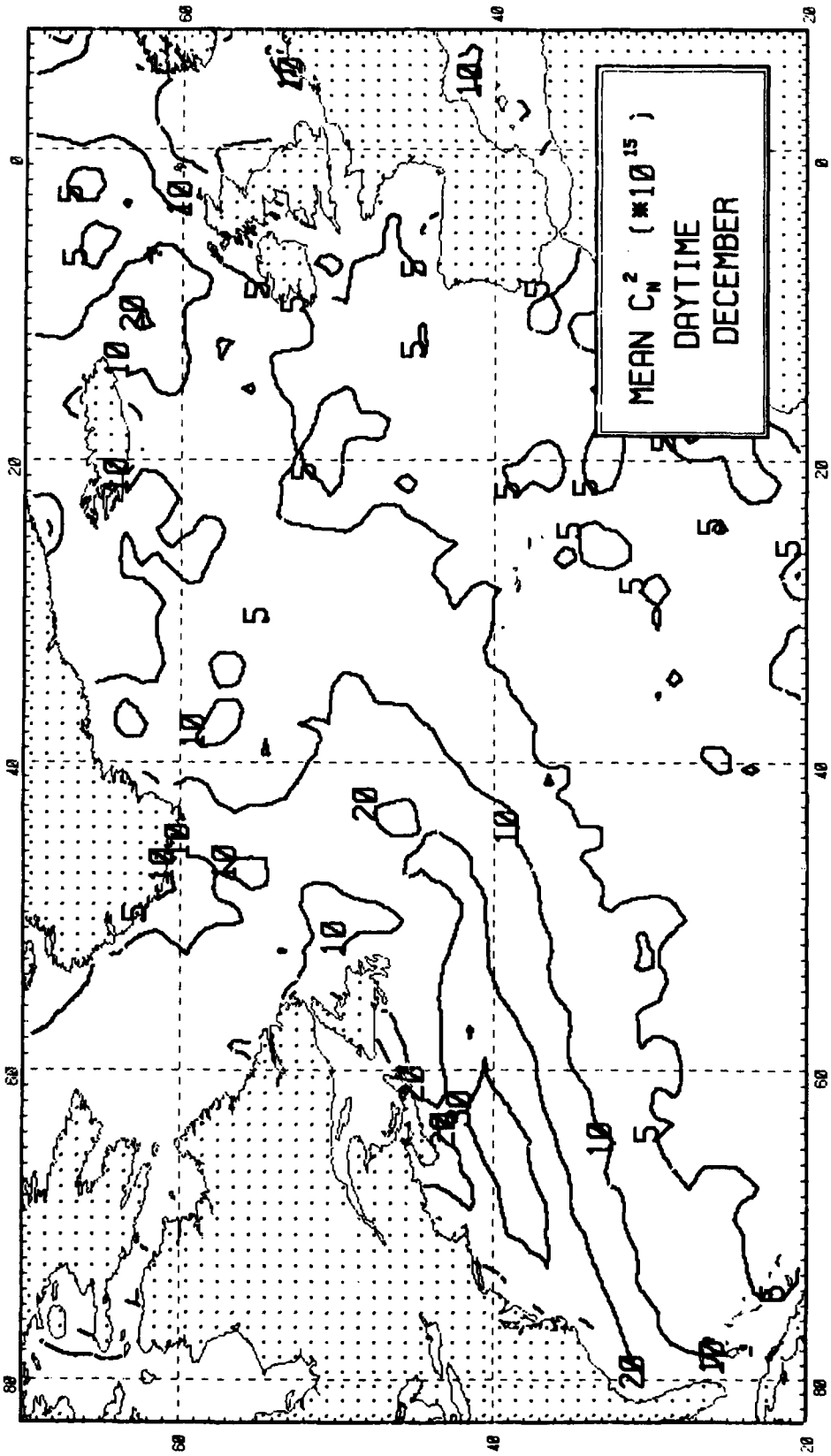


FIGURE 23



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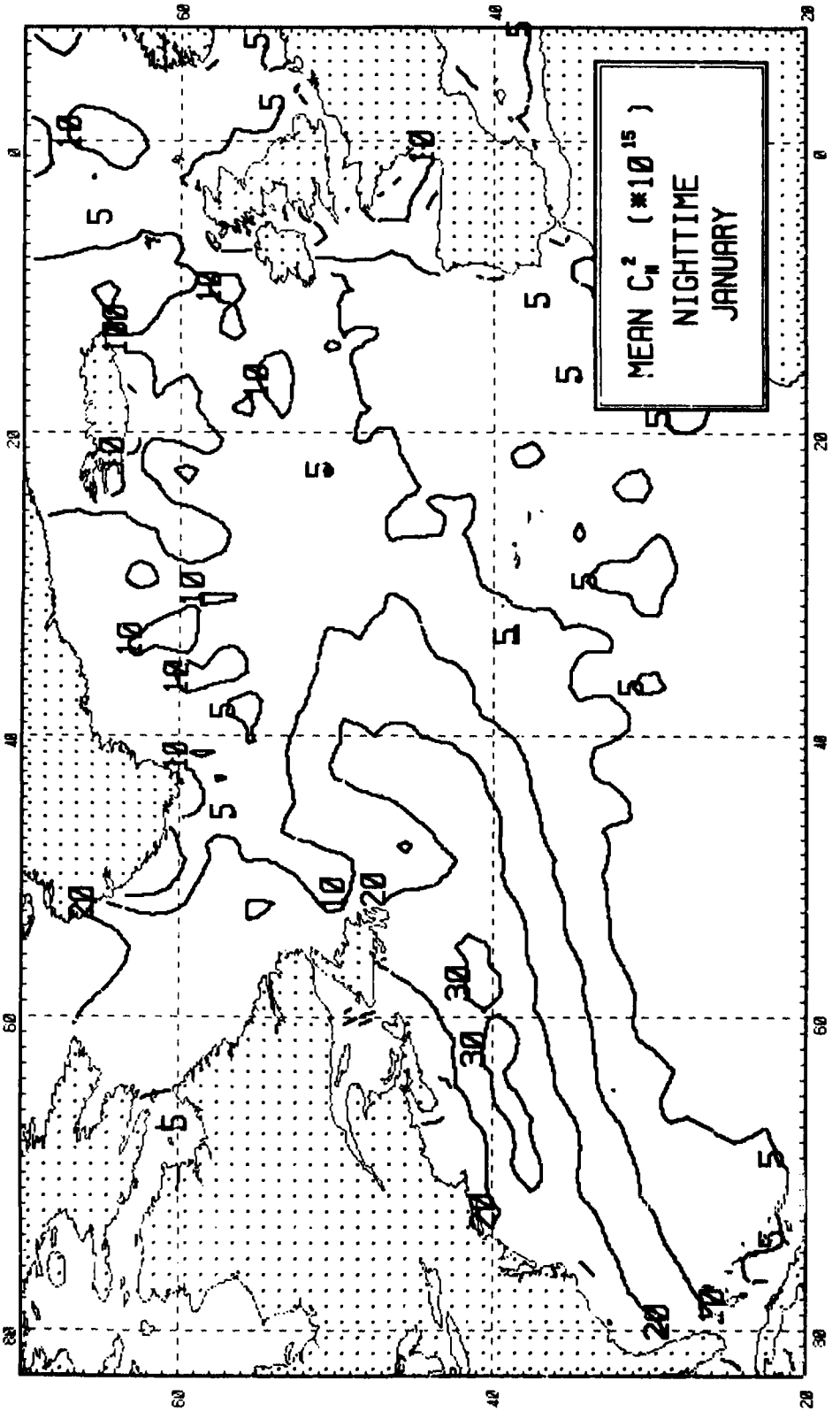


FIGURE 25

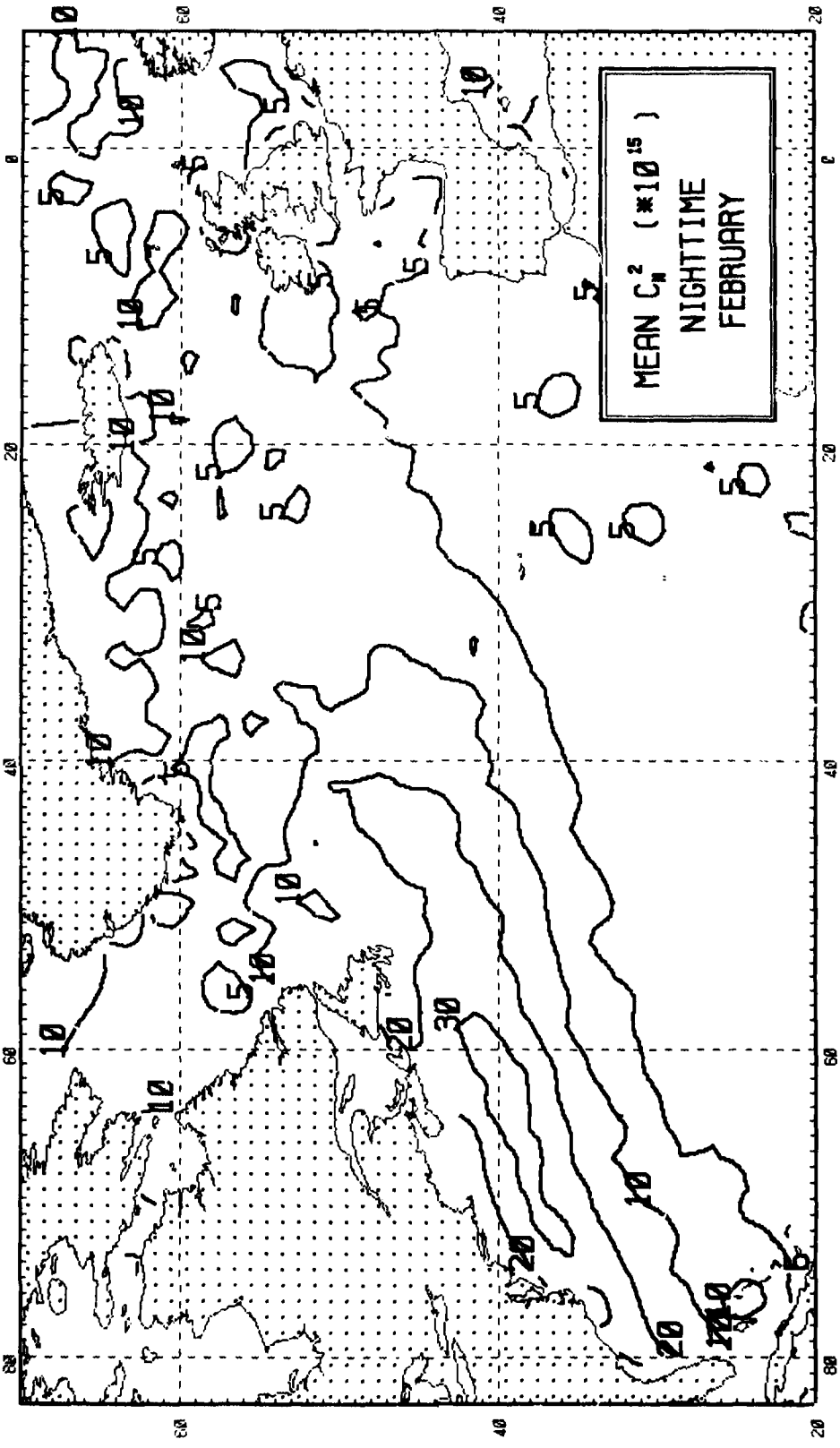


FIGURE 26

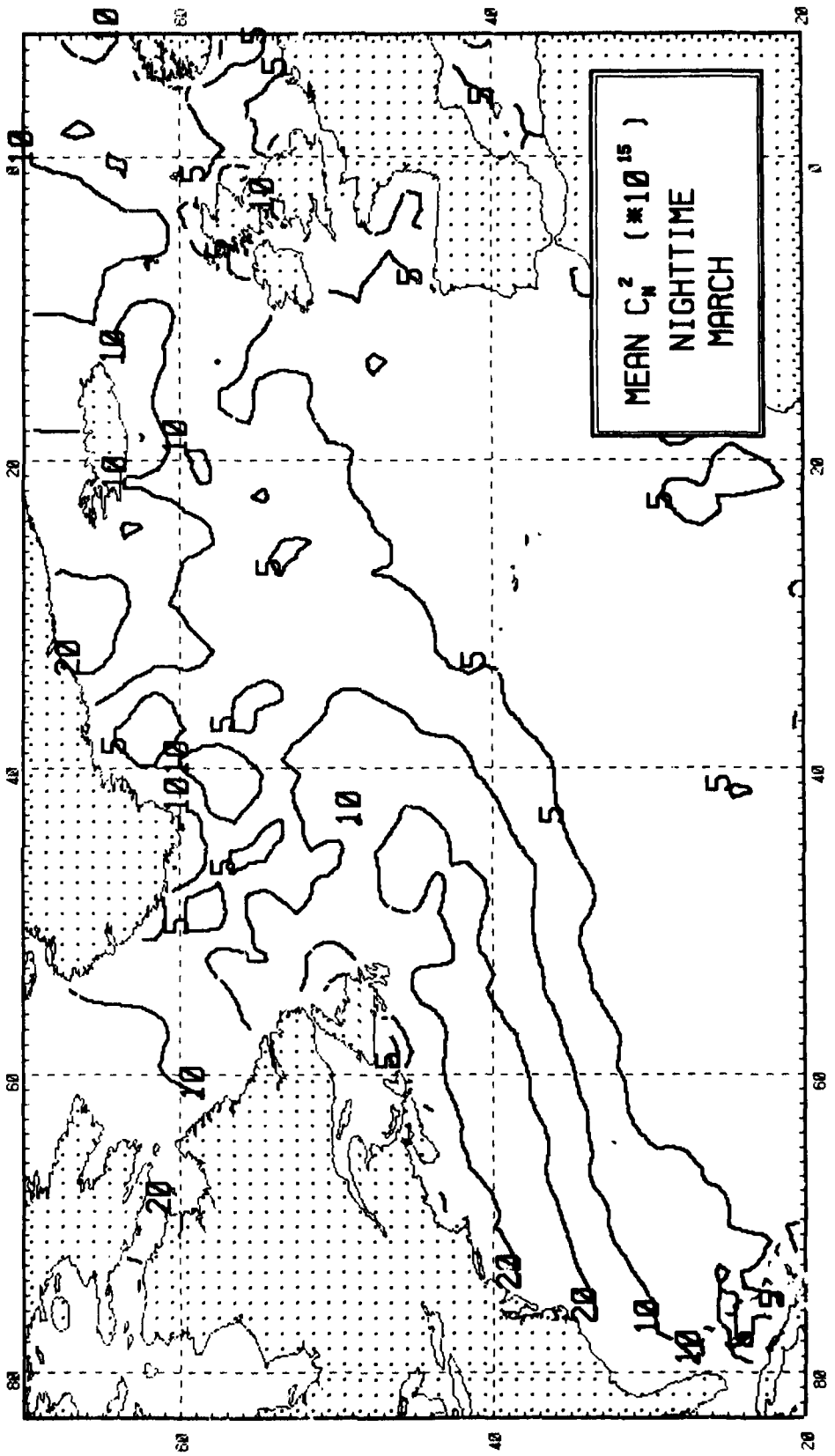


FIGURE 27

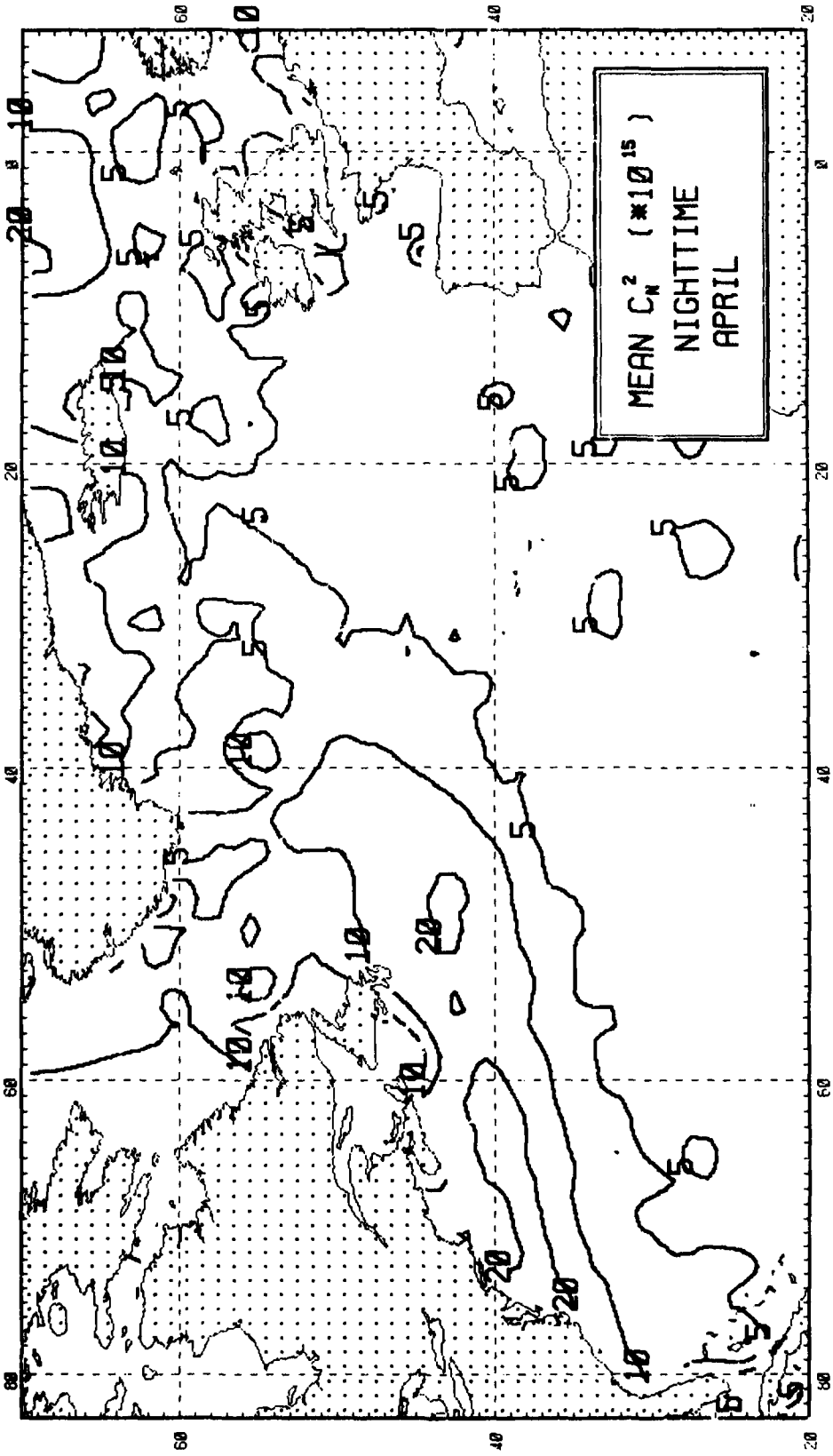
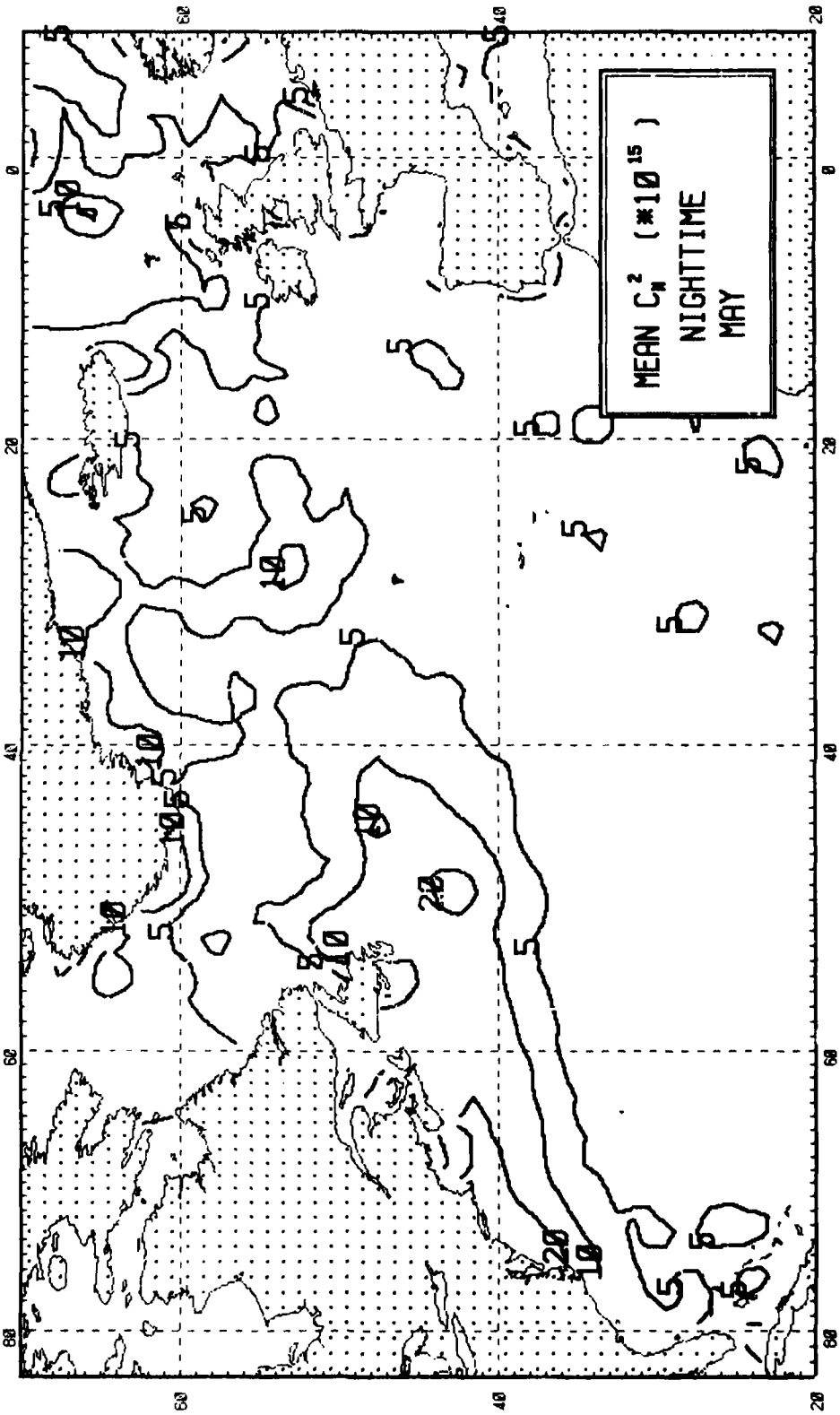


FIGURE 28



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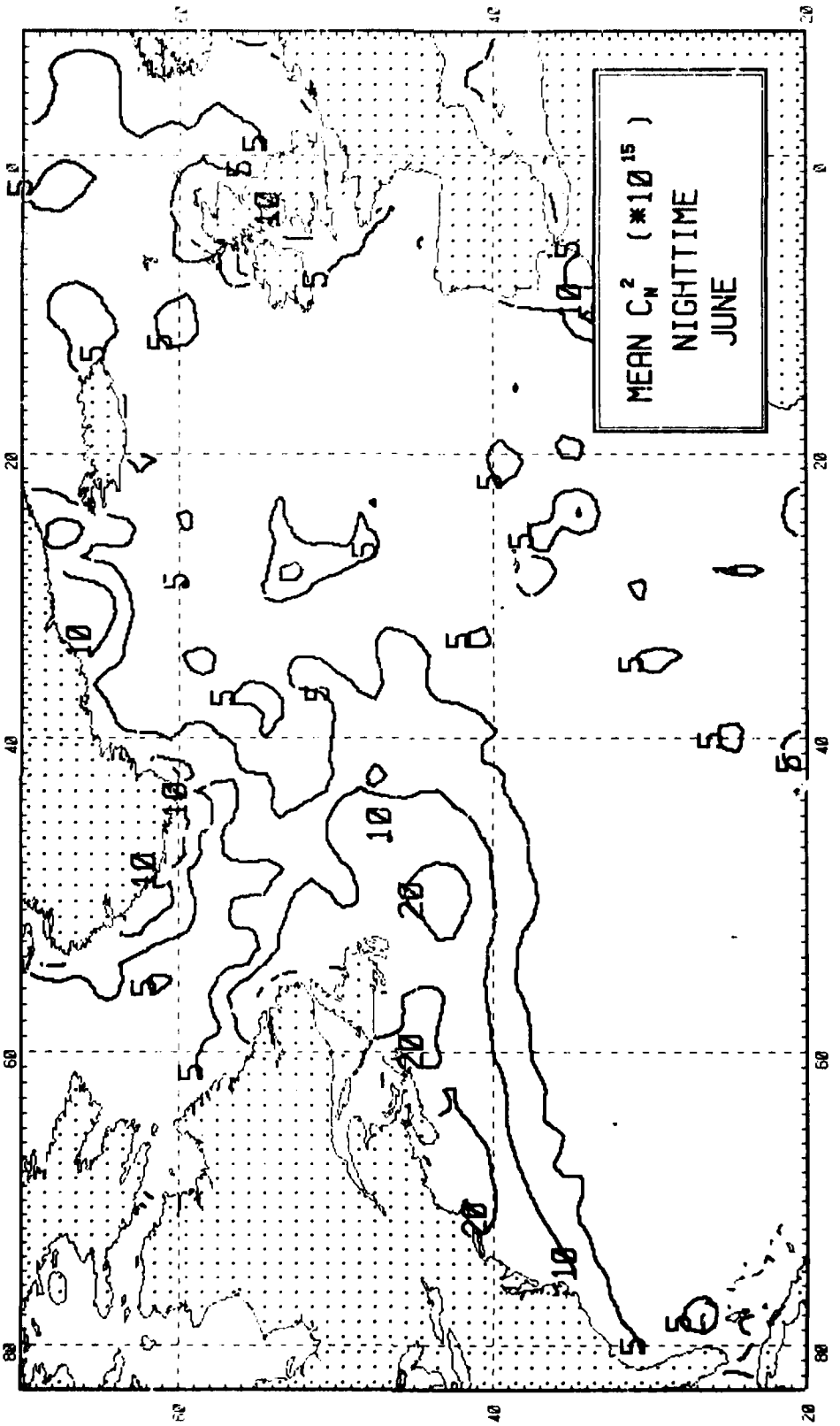


FIGURE 30

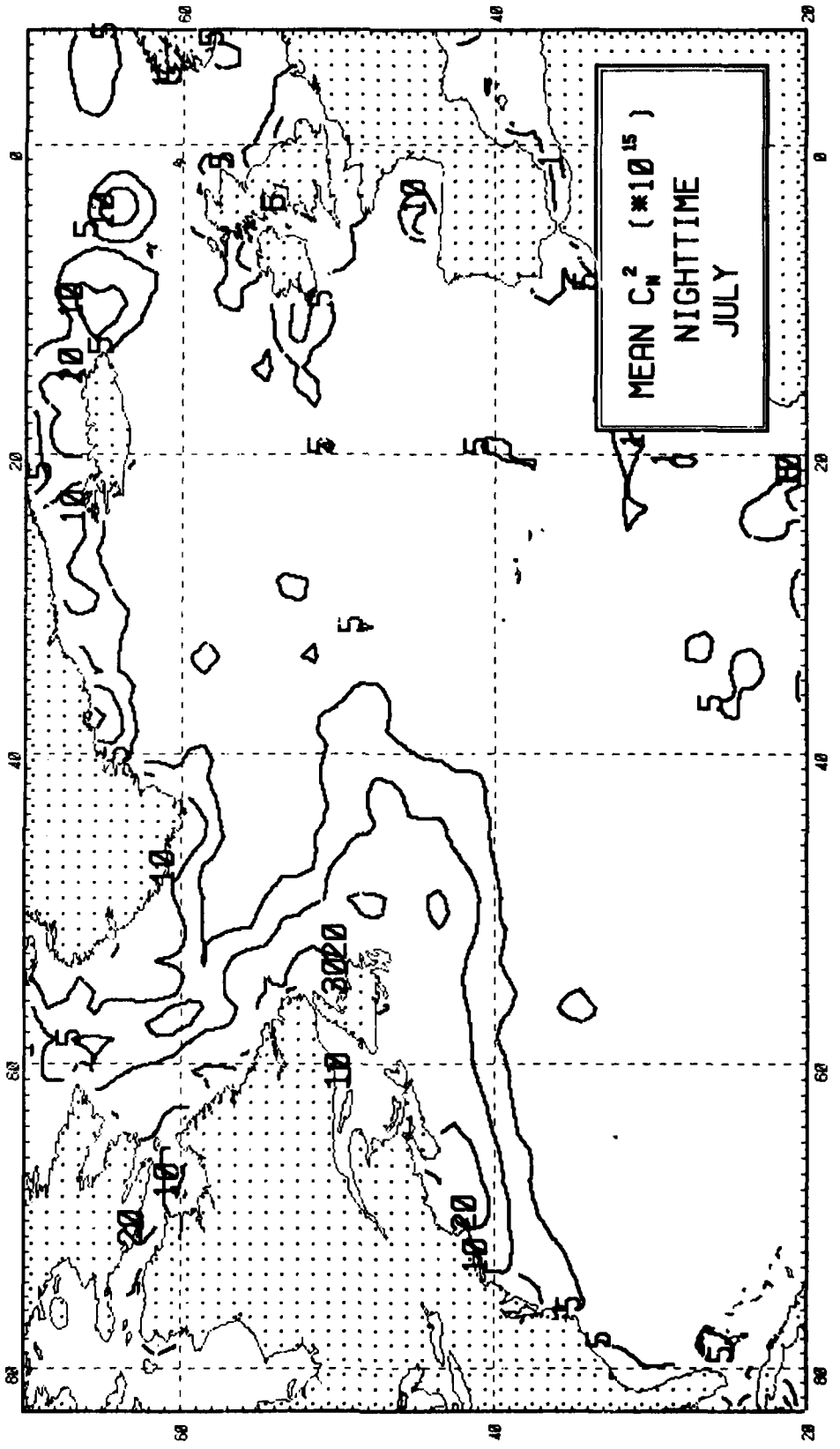


FIGURE 31

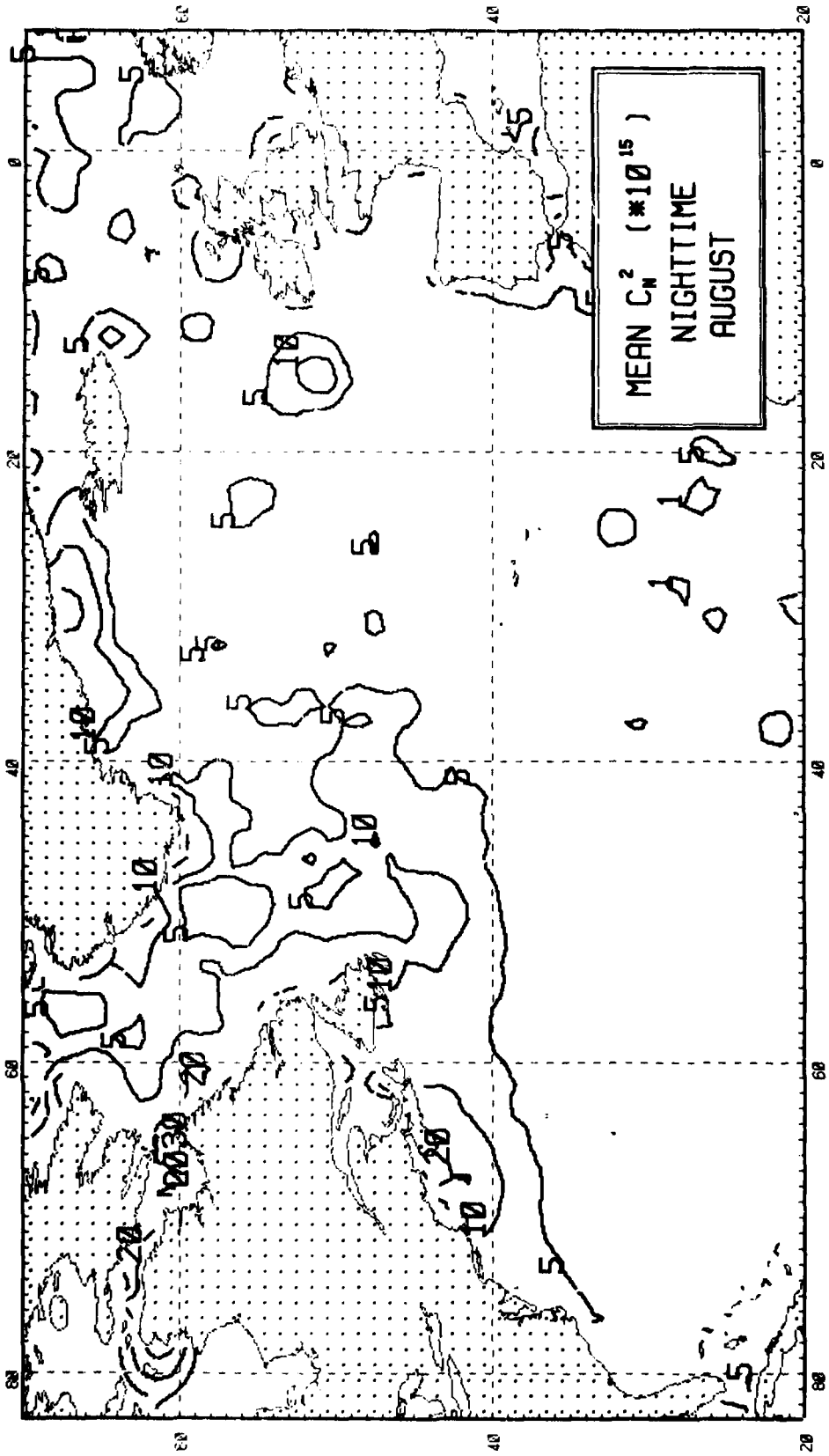


FIGURE 32

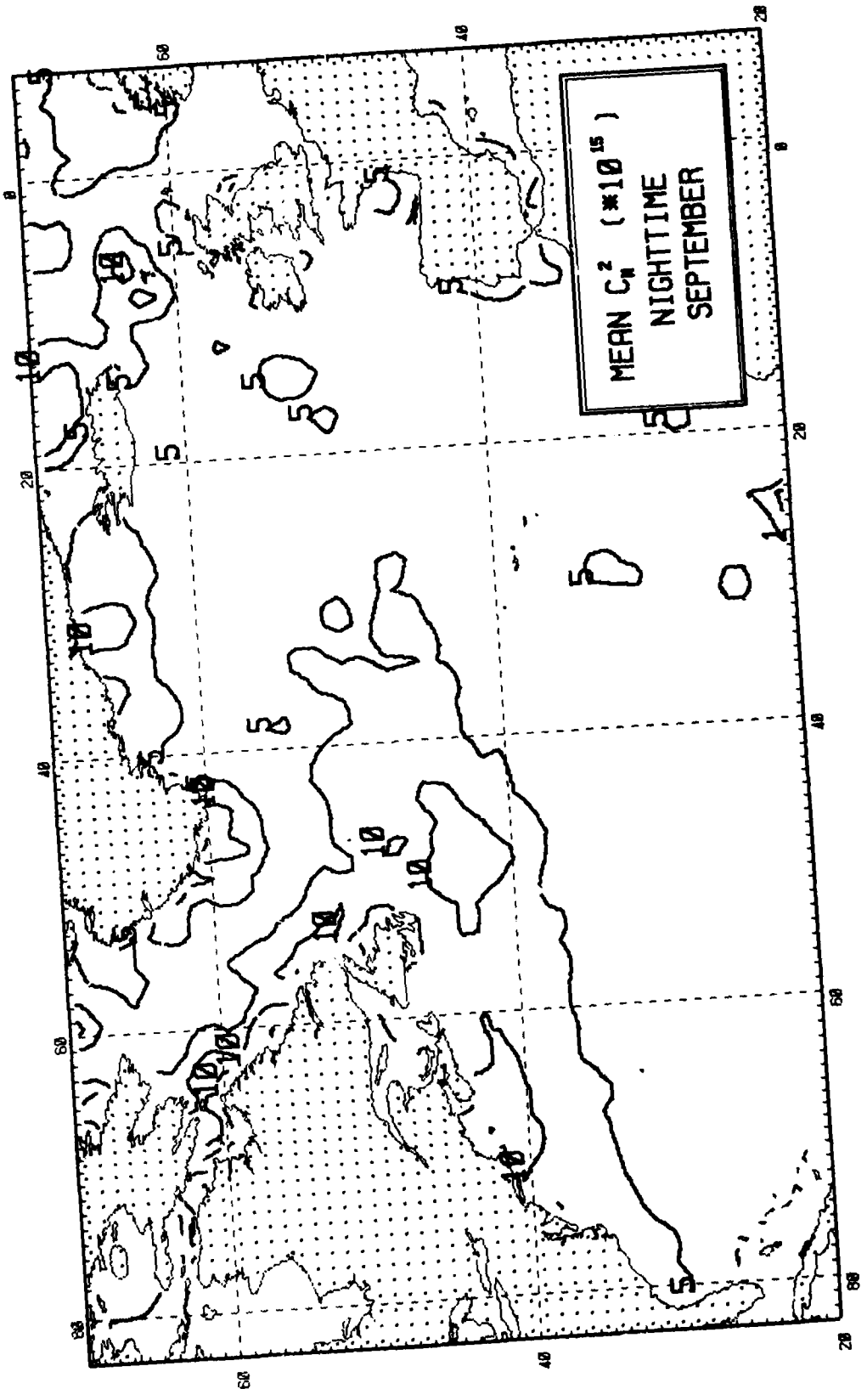


FIGURE 33

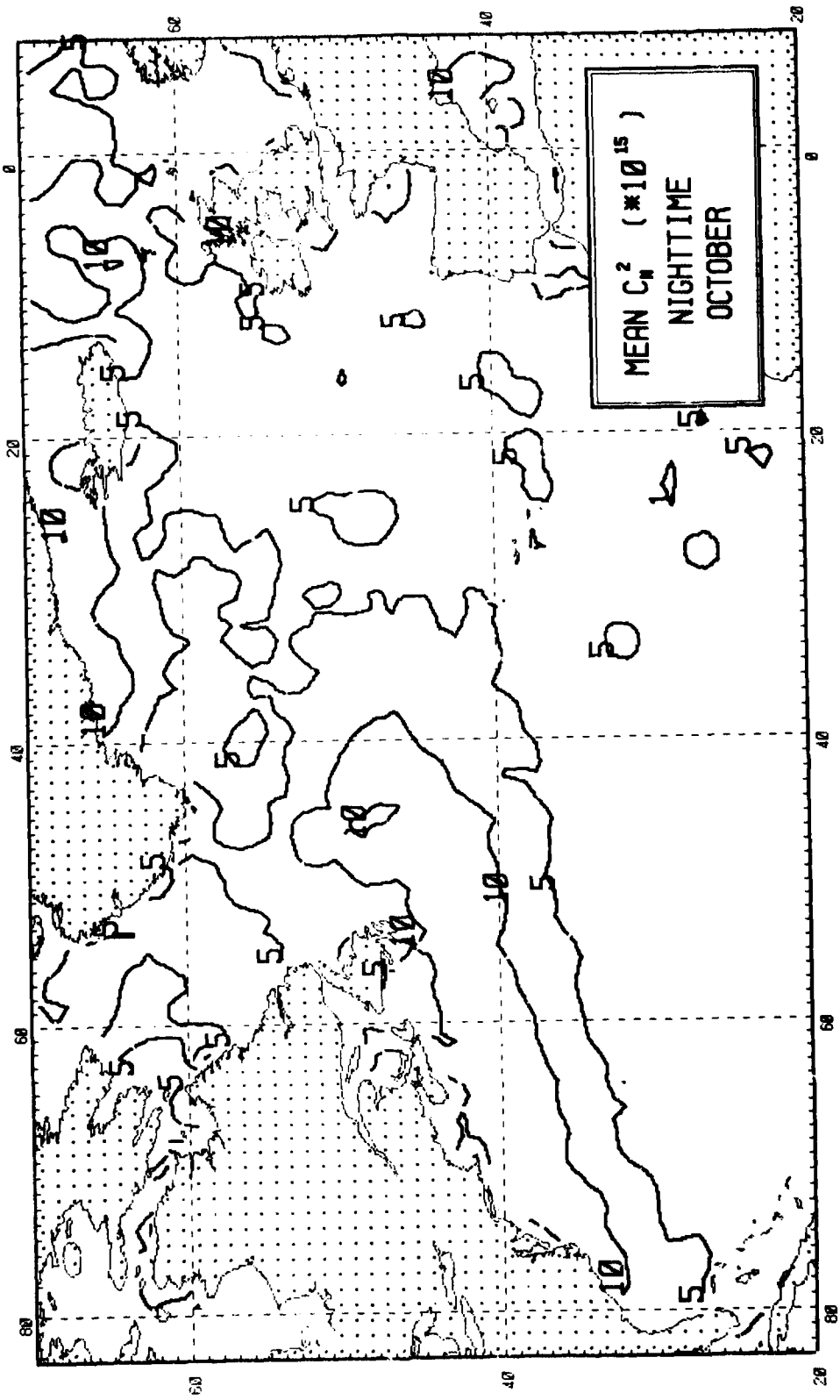


FIGURE 34

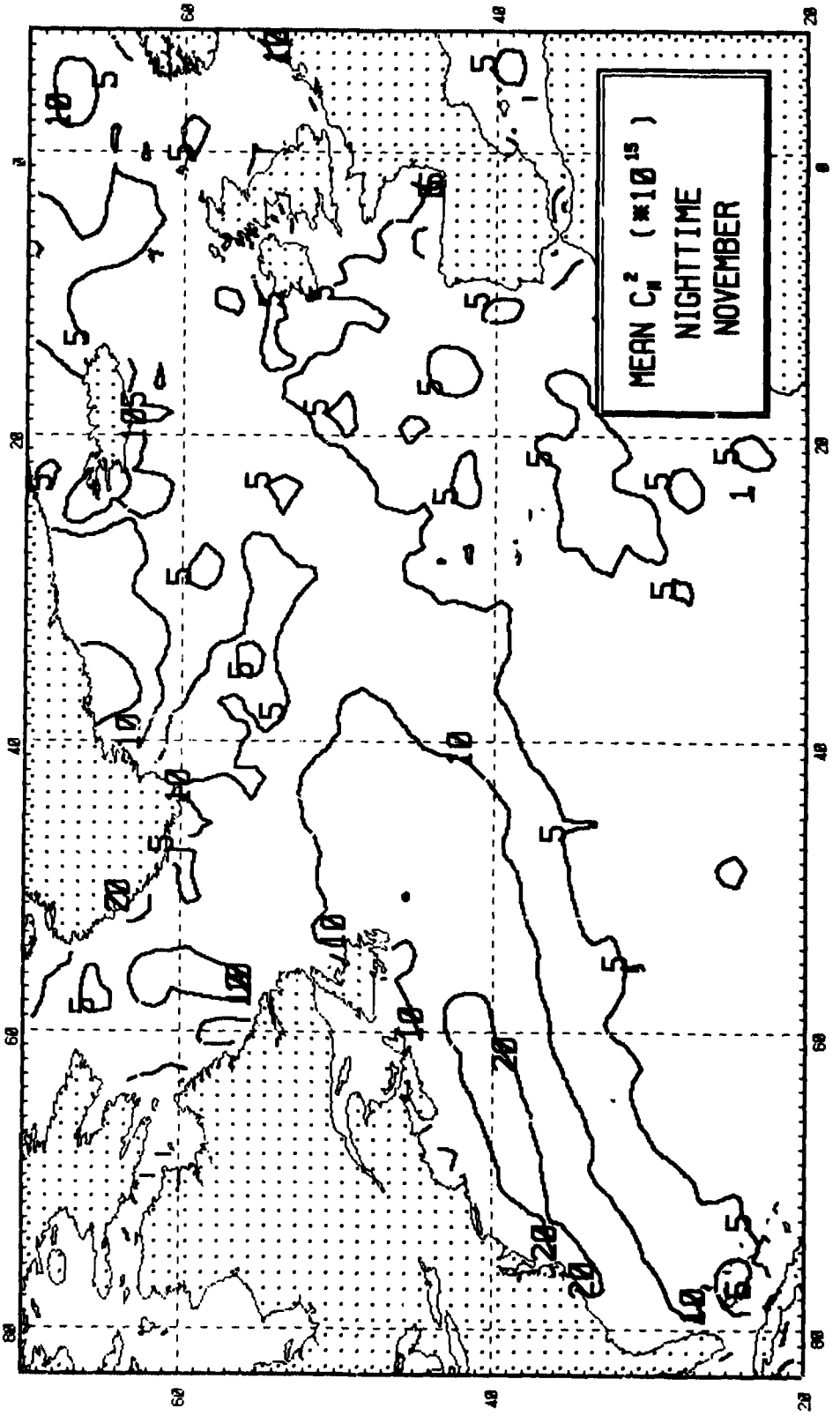


FIGURE 35

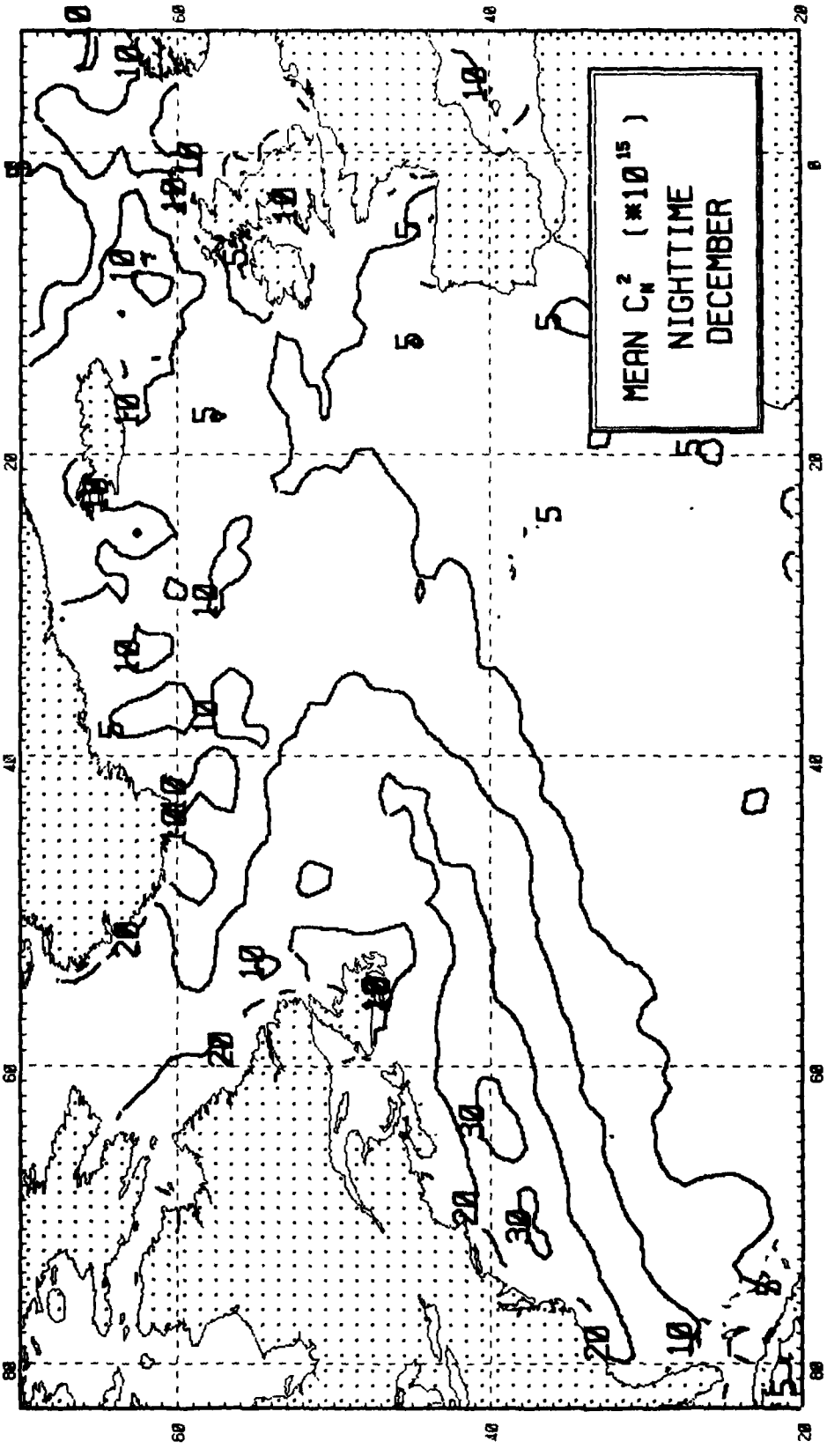


FIGURE 36

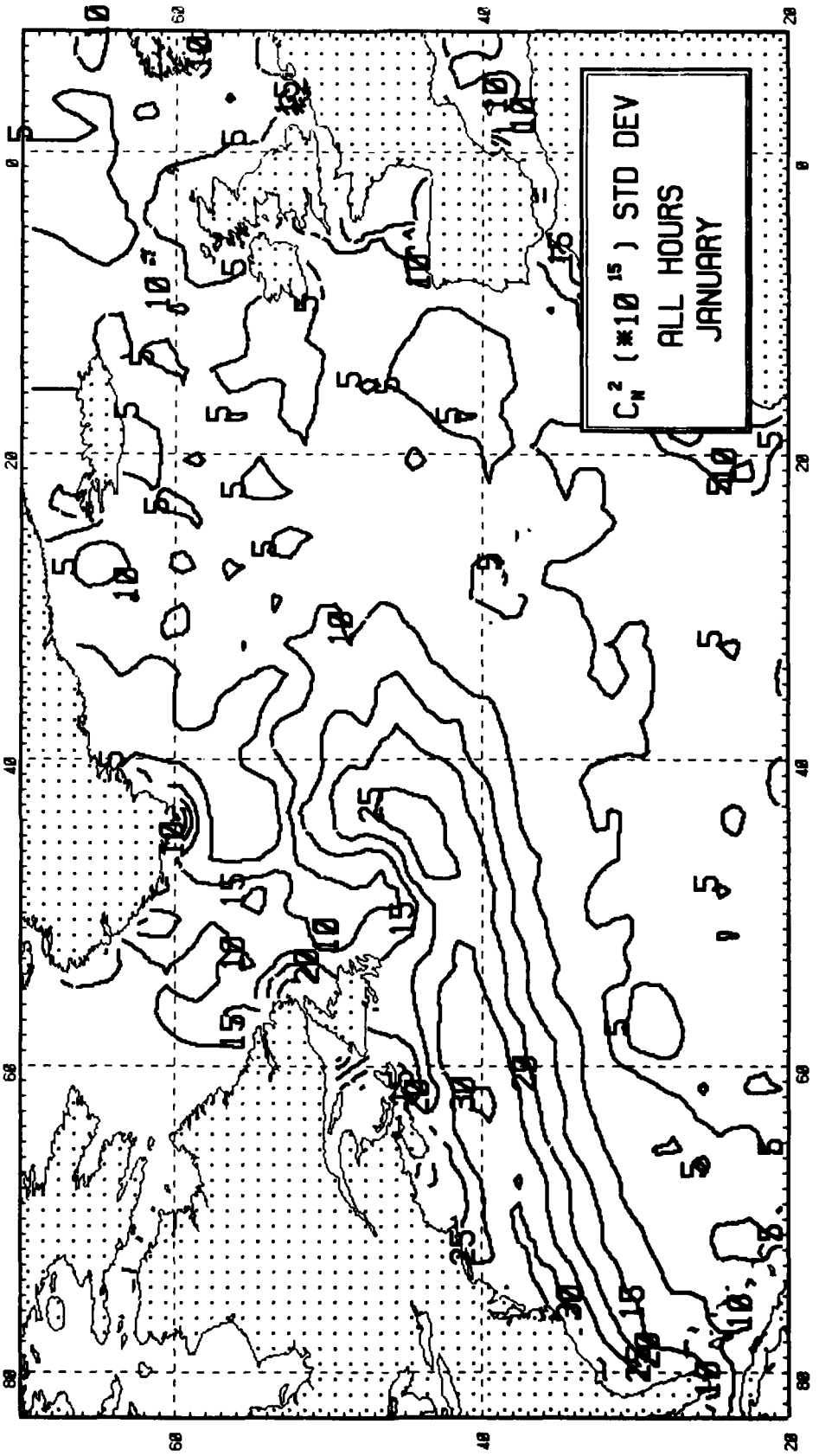


FIGURE 37

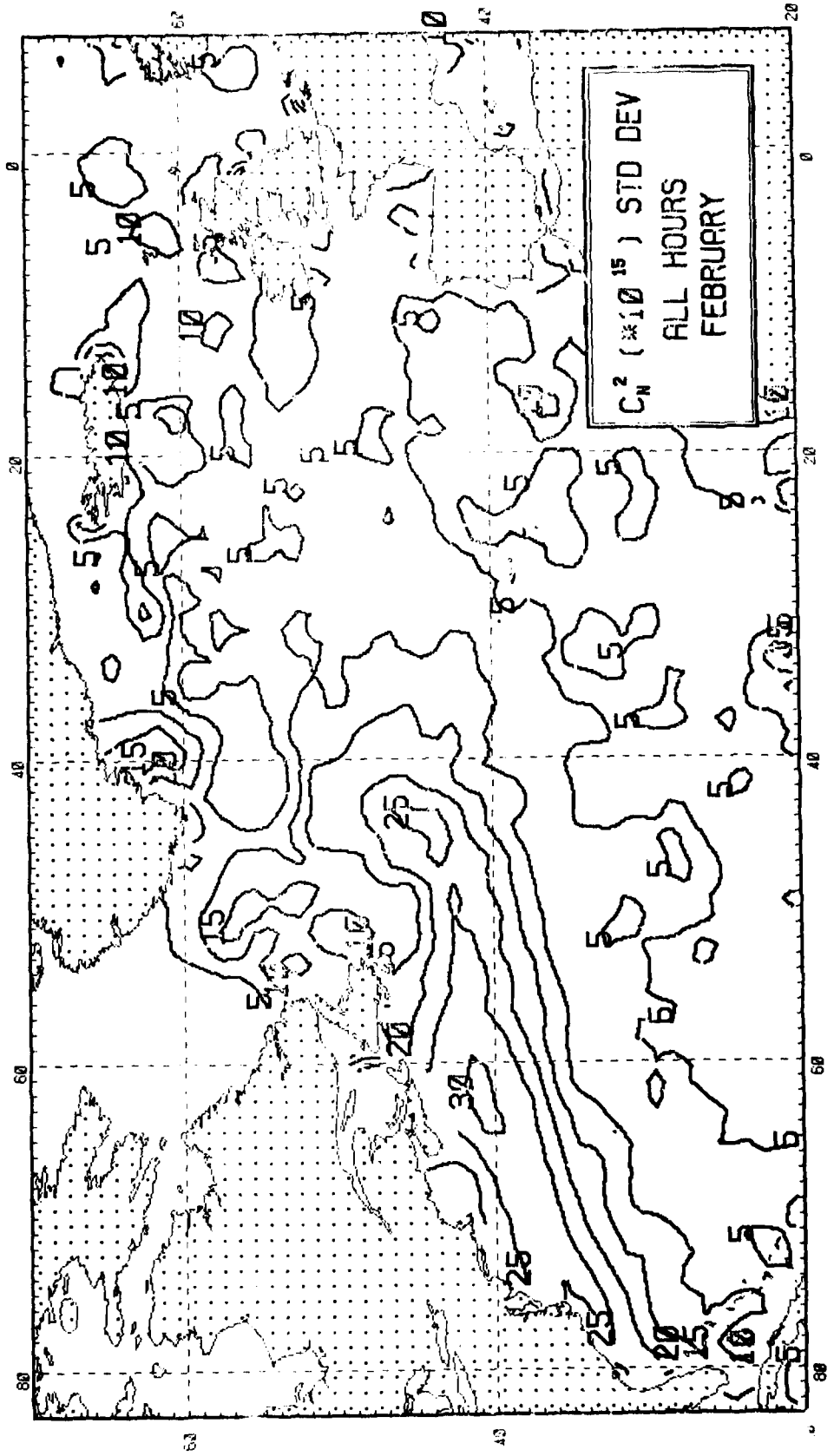


FIGURE 38

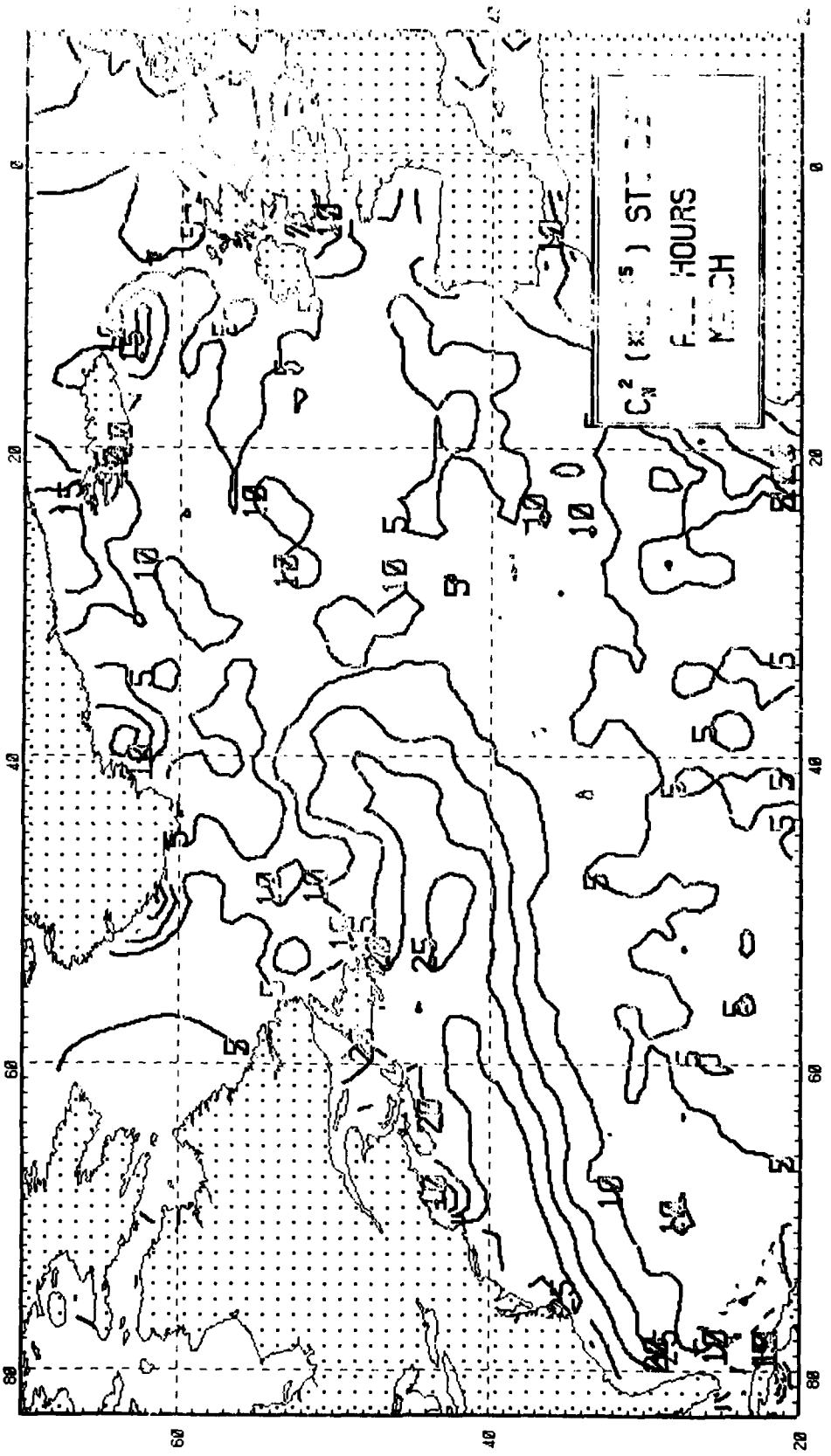


FIGURE 39

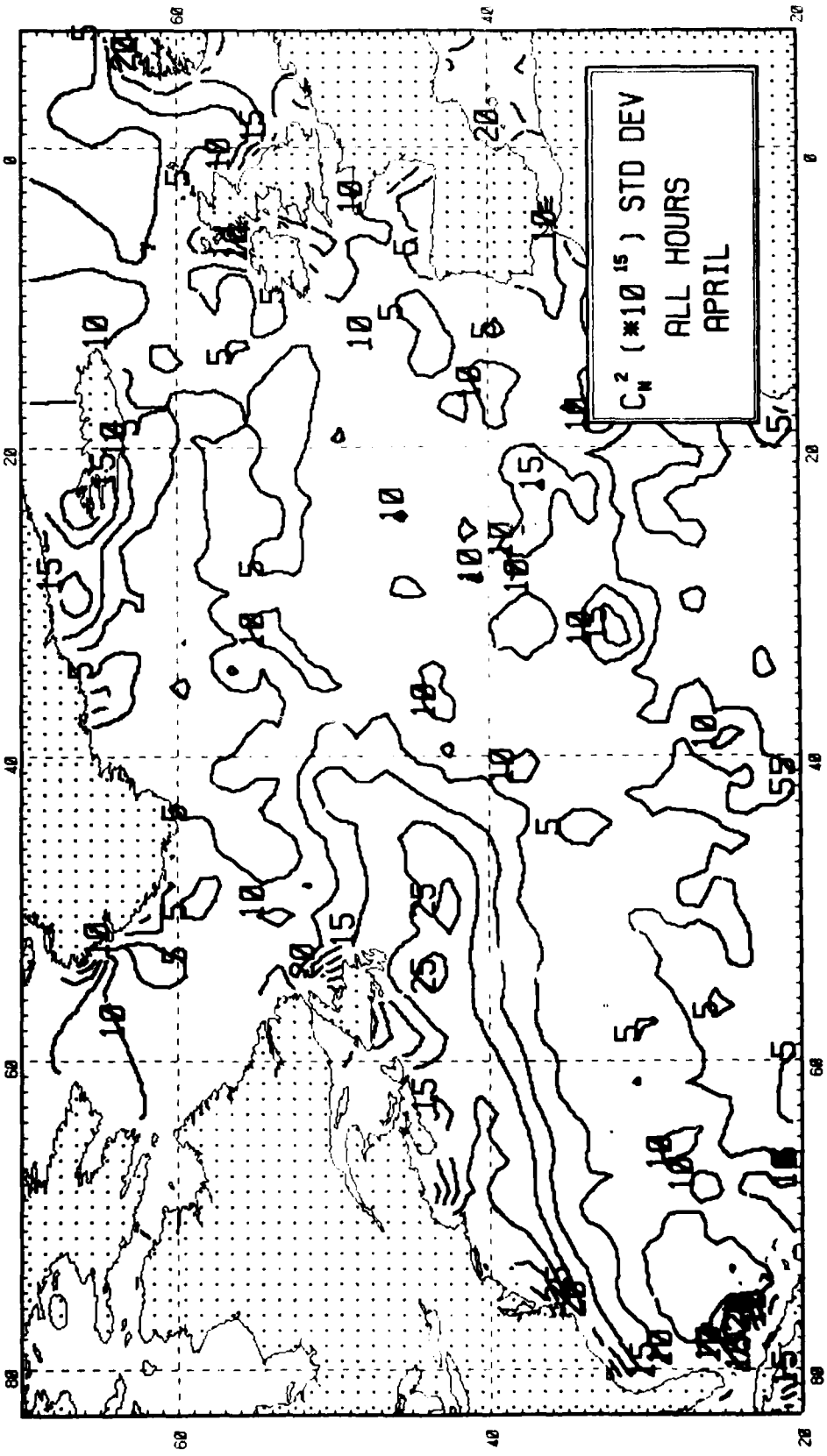


FIGURE 40

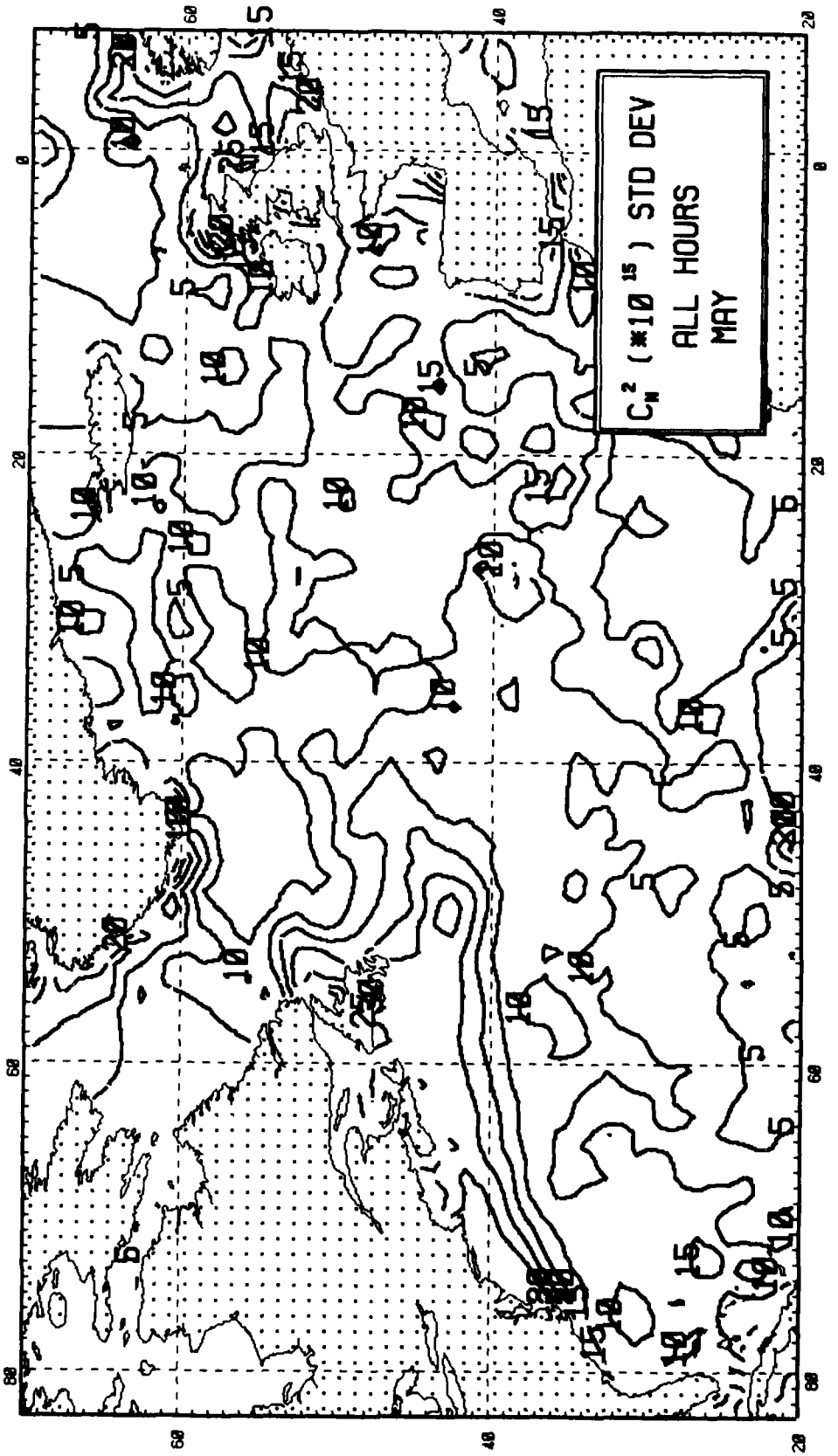


FIGURE 41

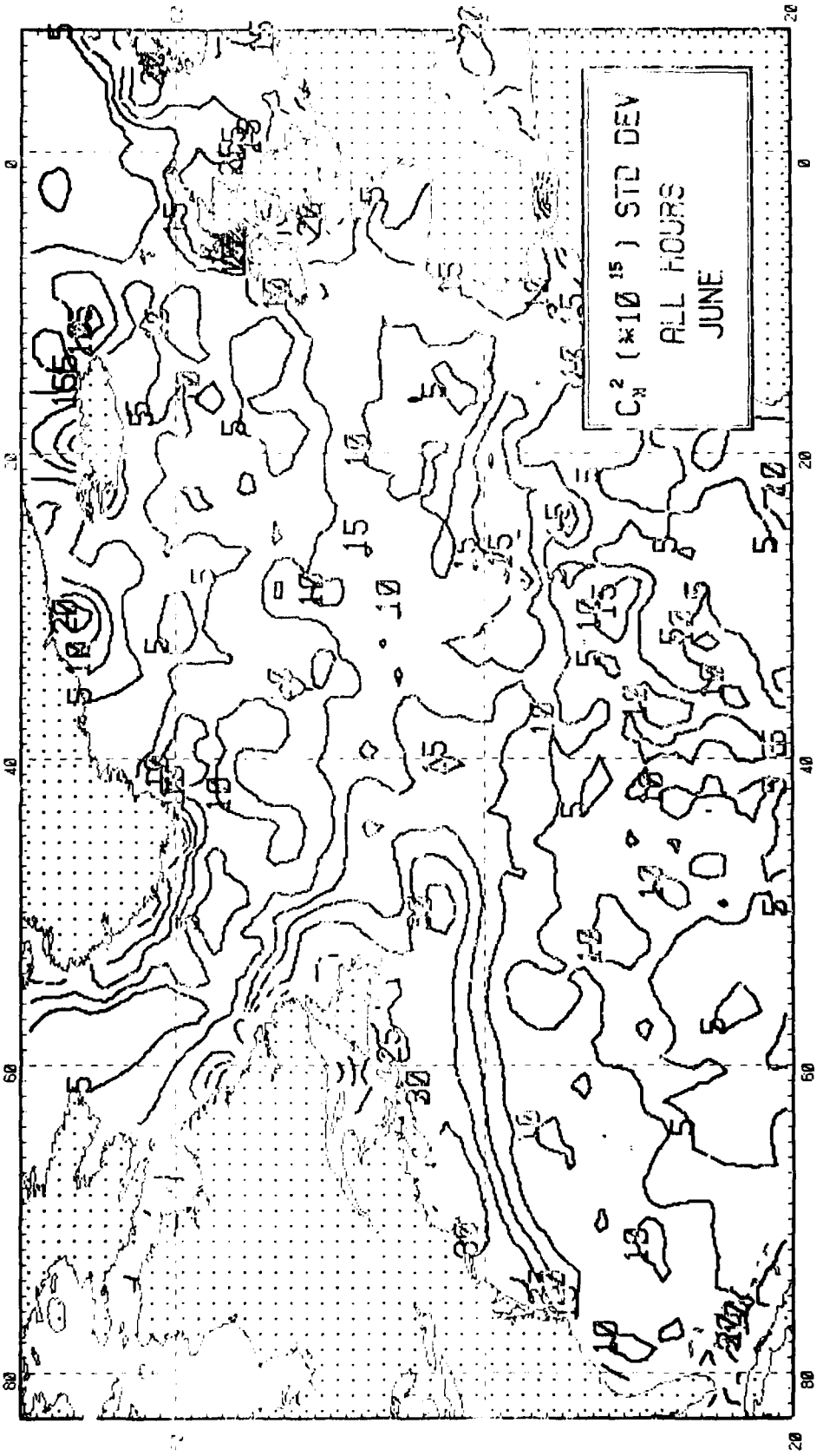


FIGURE 42

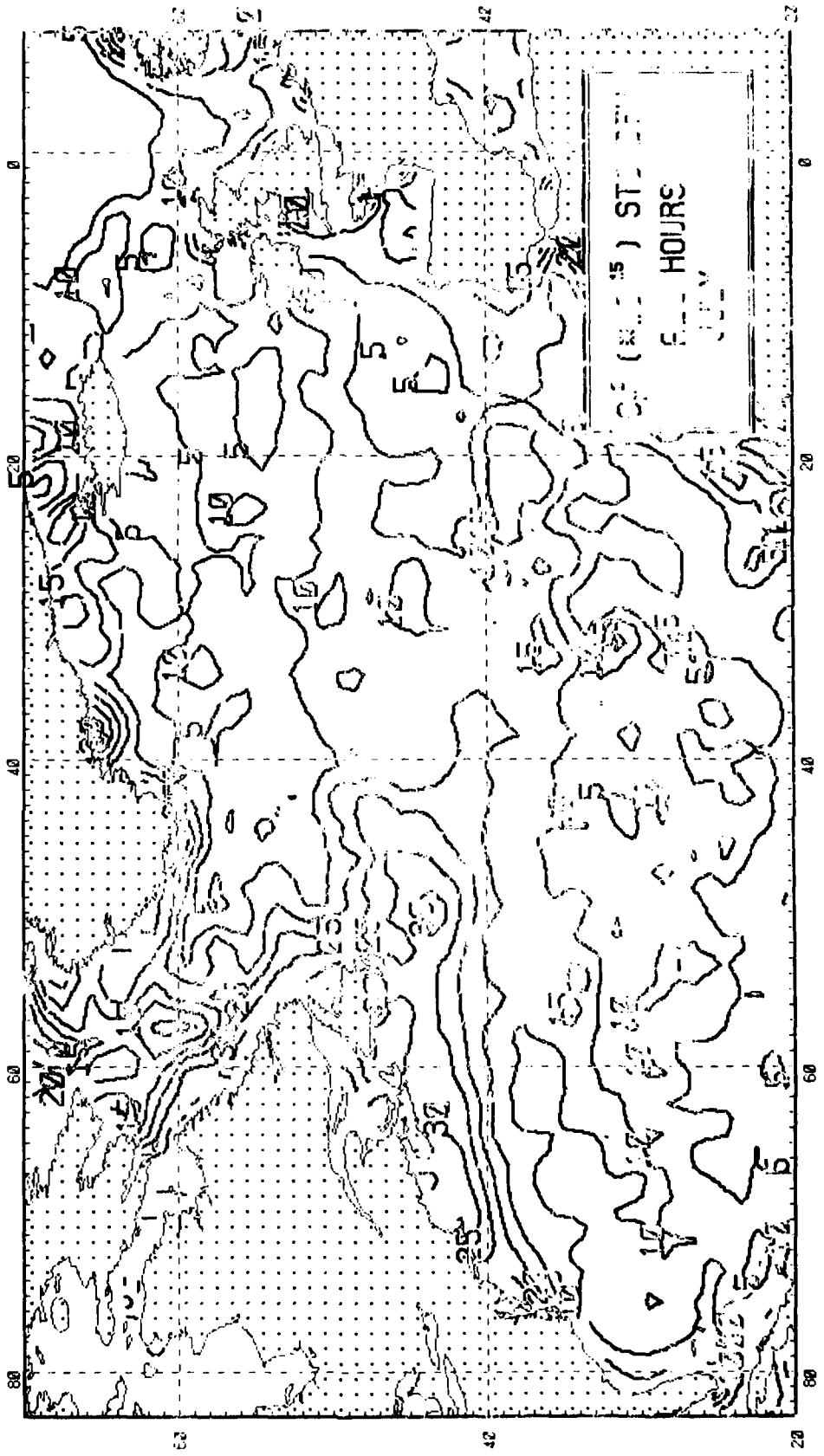


FIGURE 43

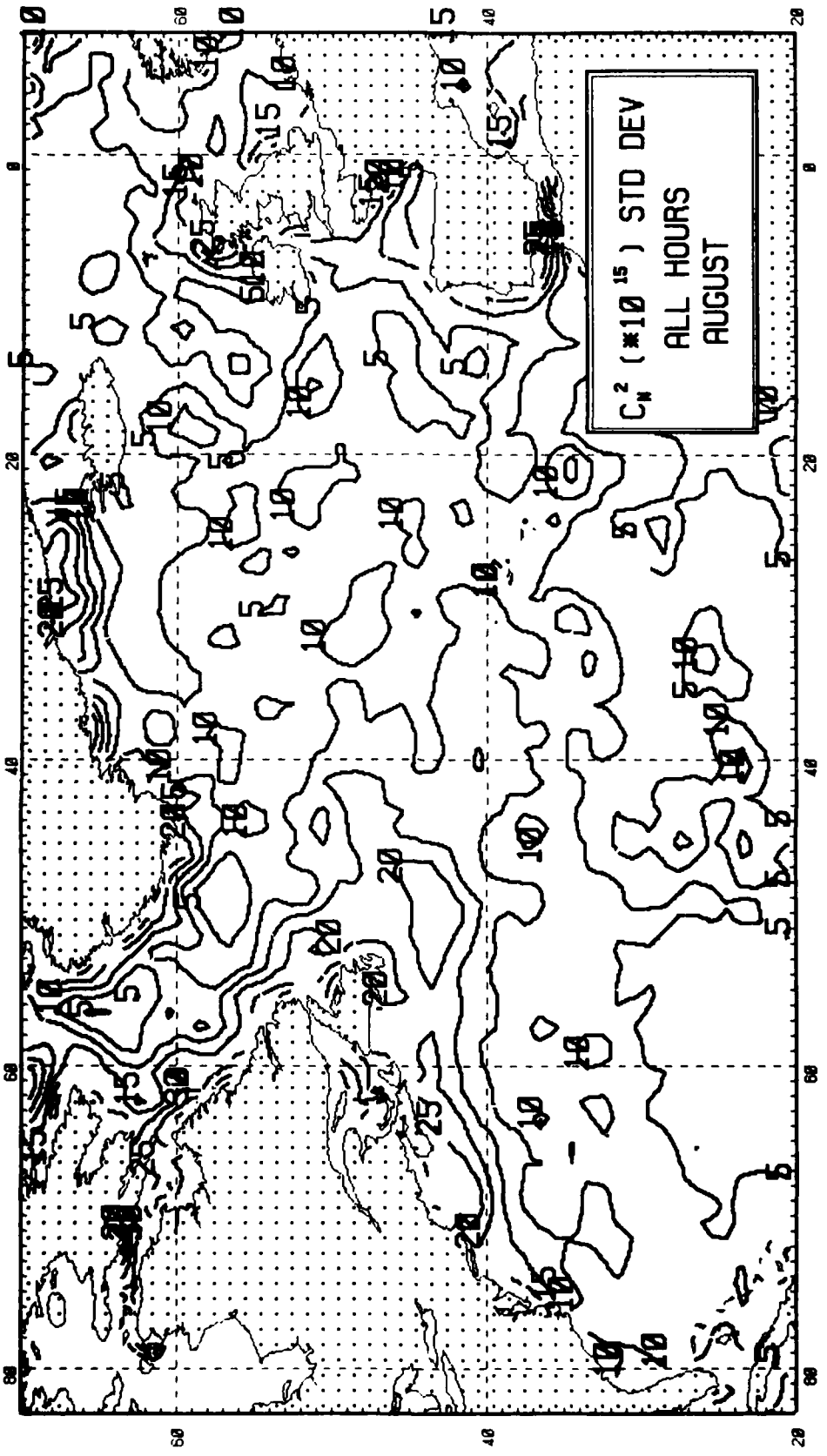


FIGURE 44

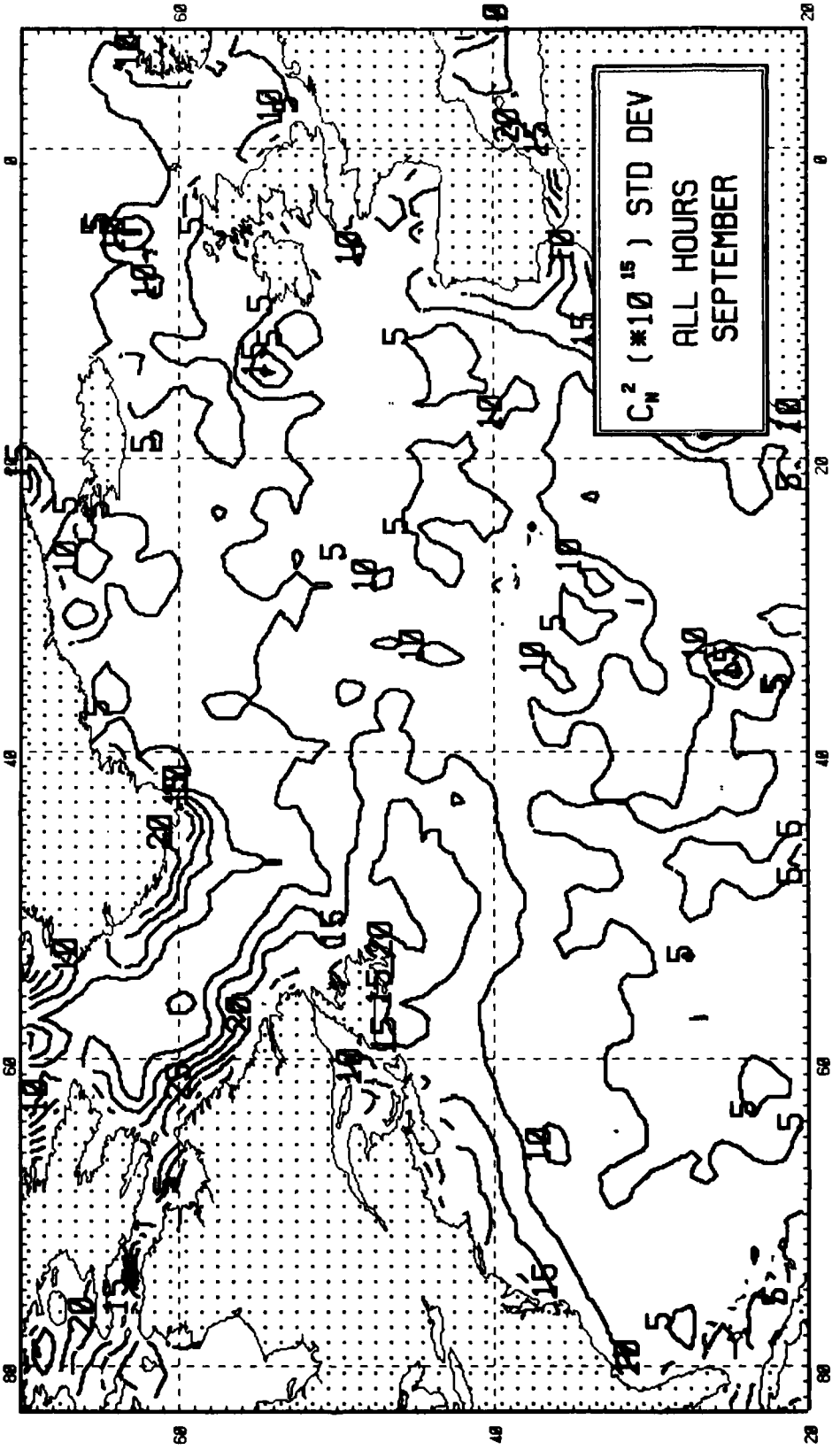


FIGURE 45

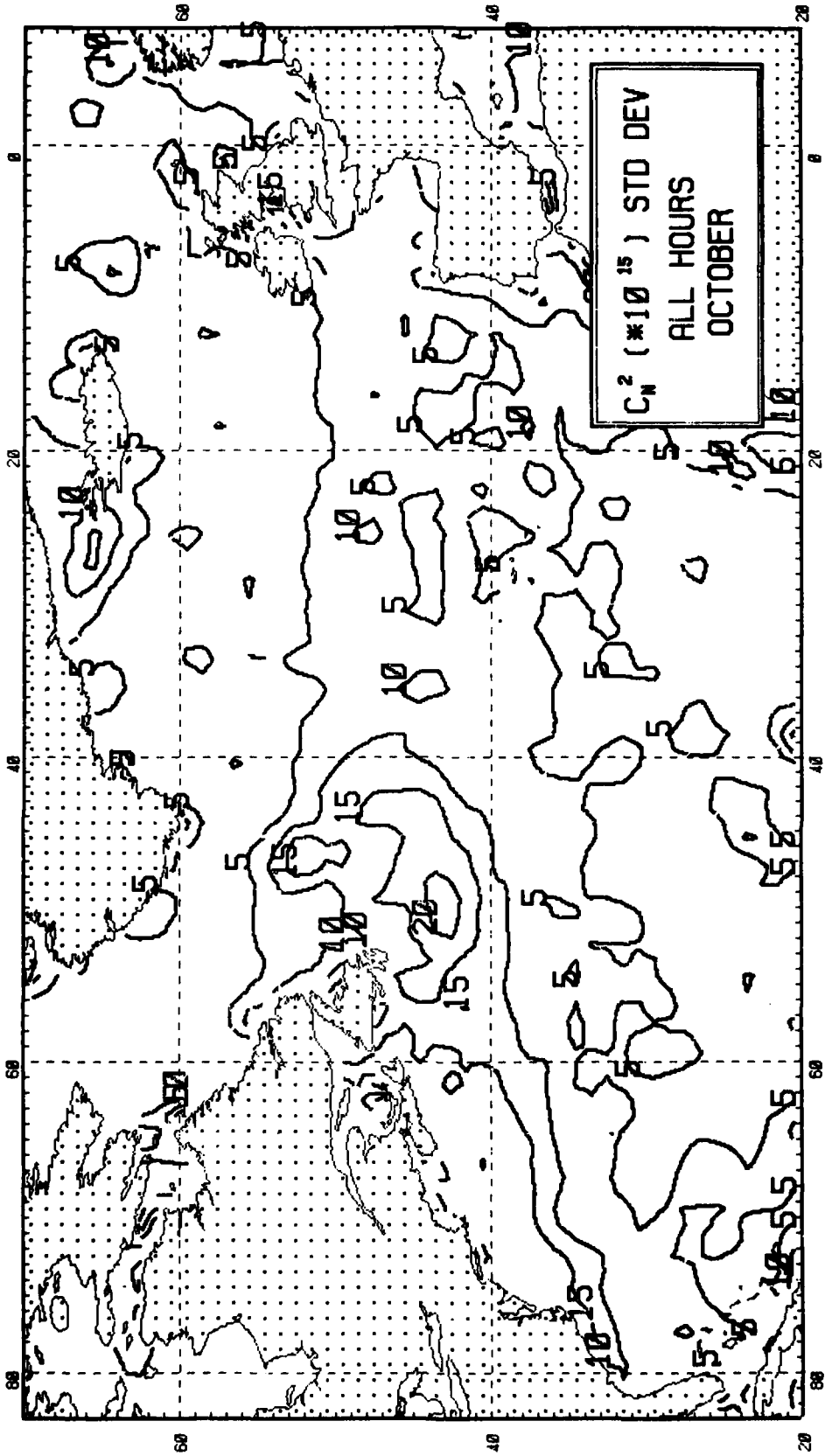


FIGURE 46

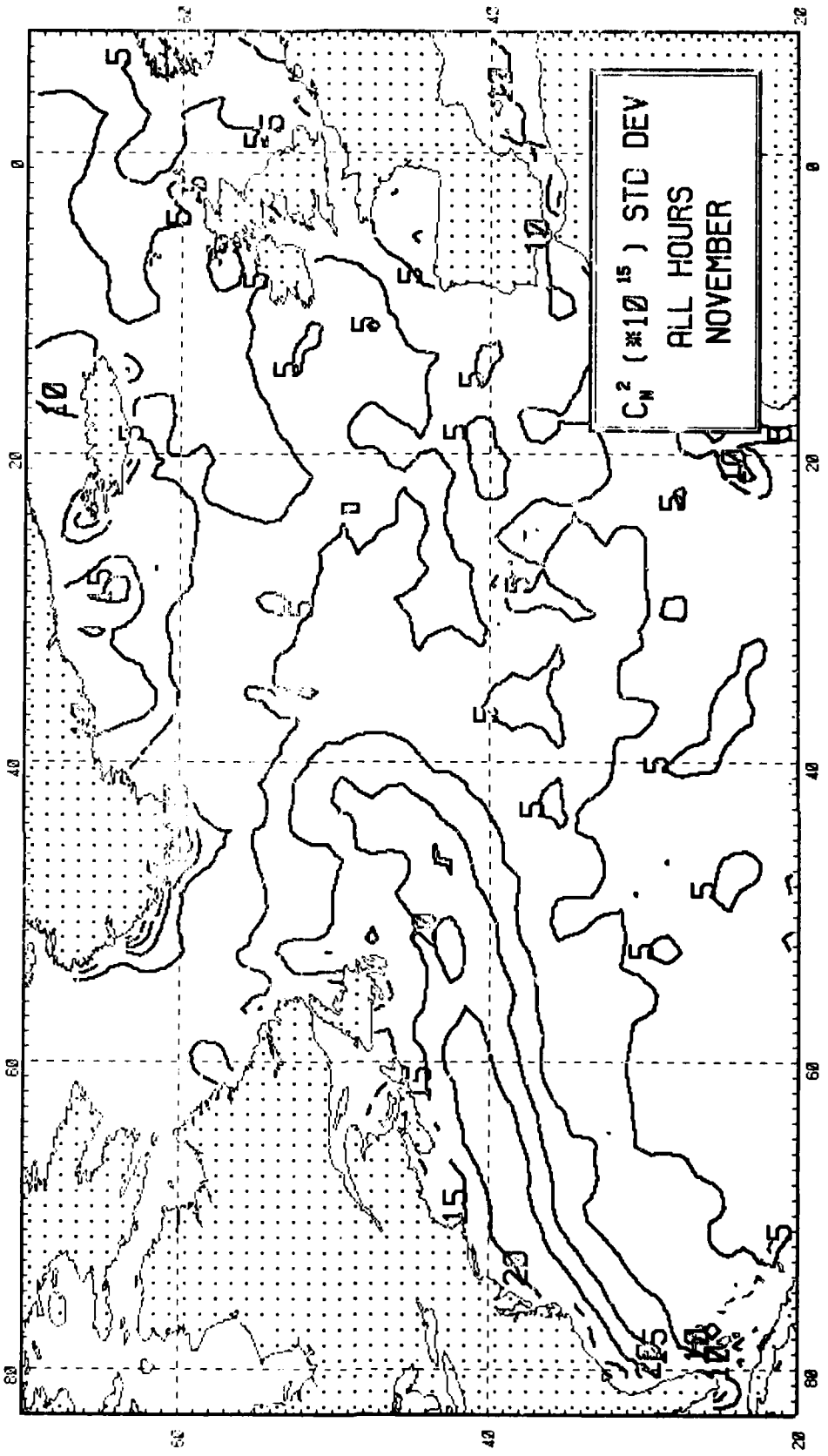


FIGURE 47

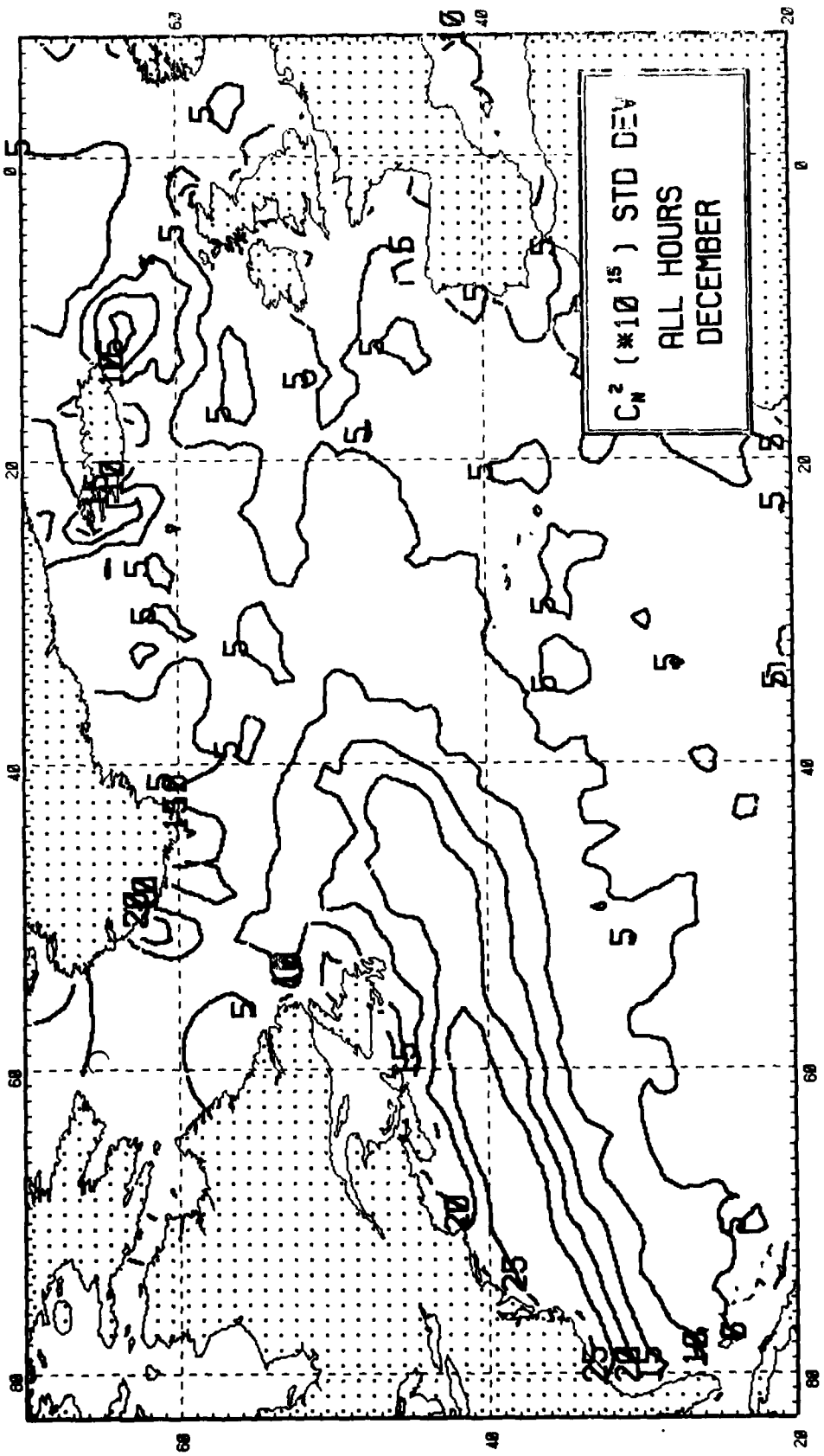


FIGURE 48

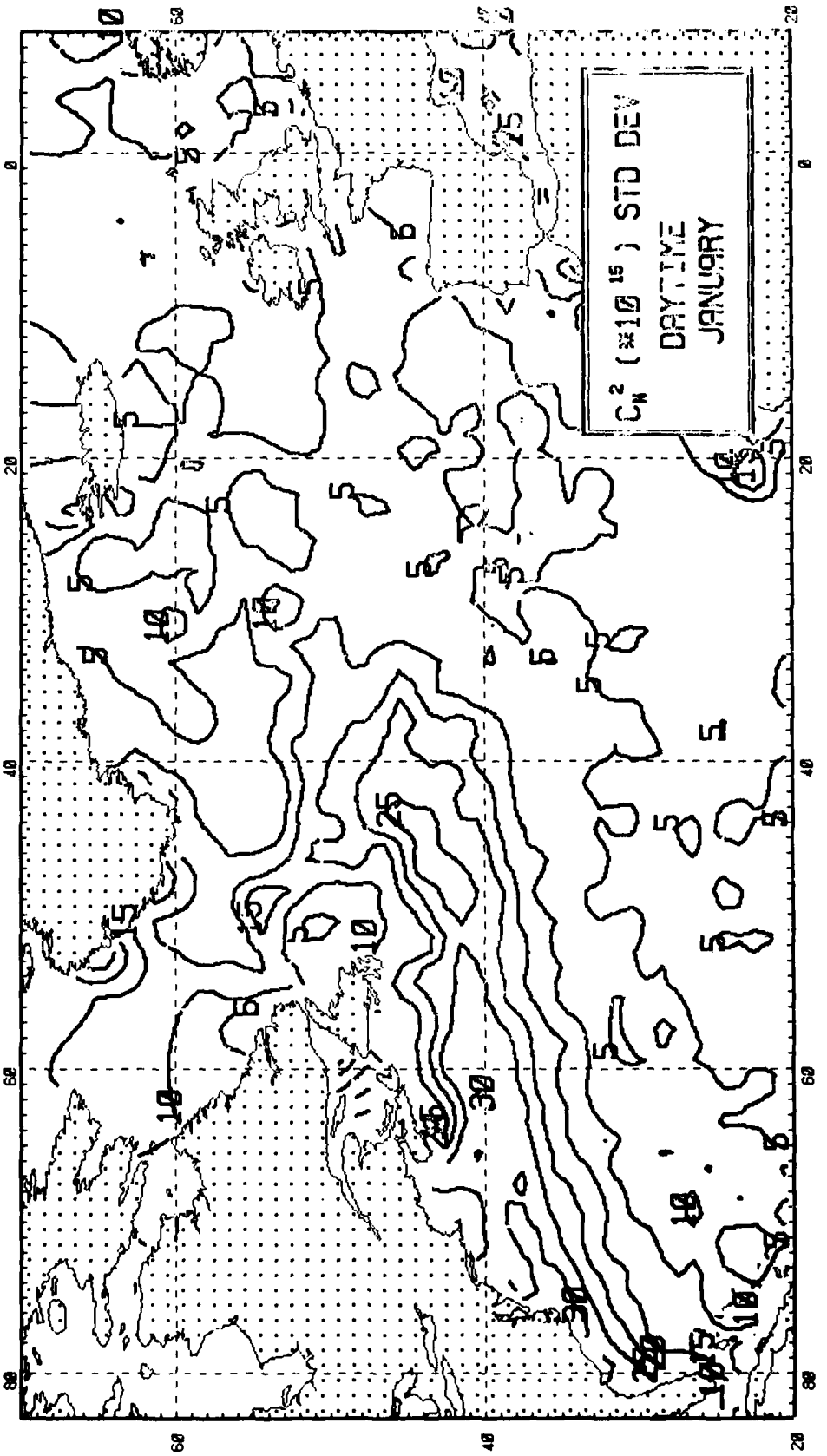


FIGURE 49

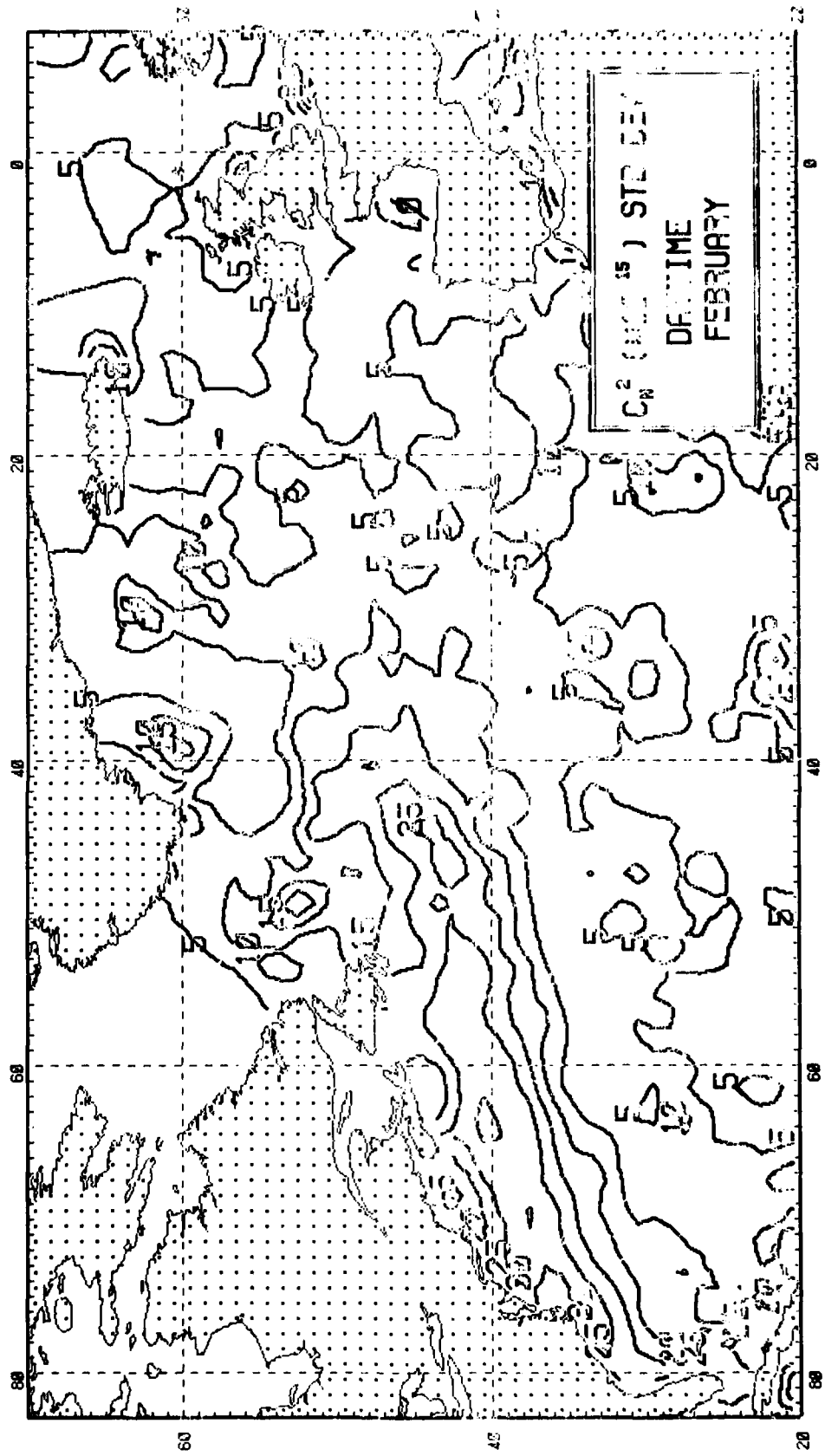


FIGURE 50

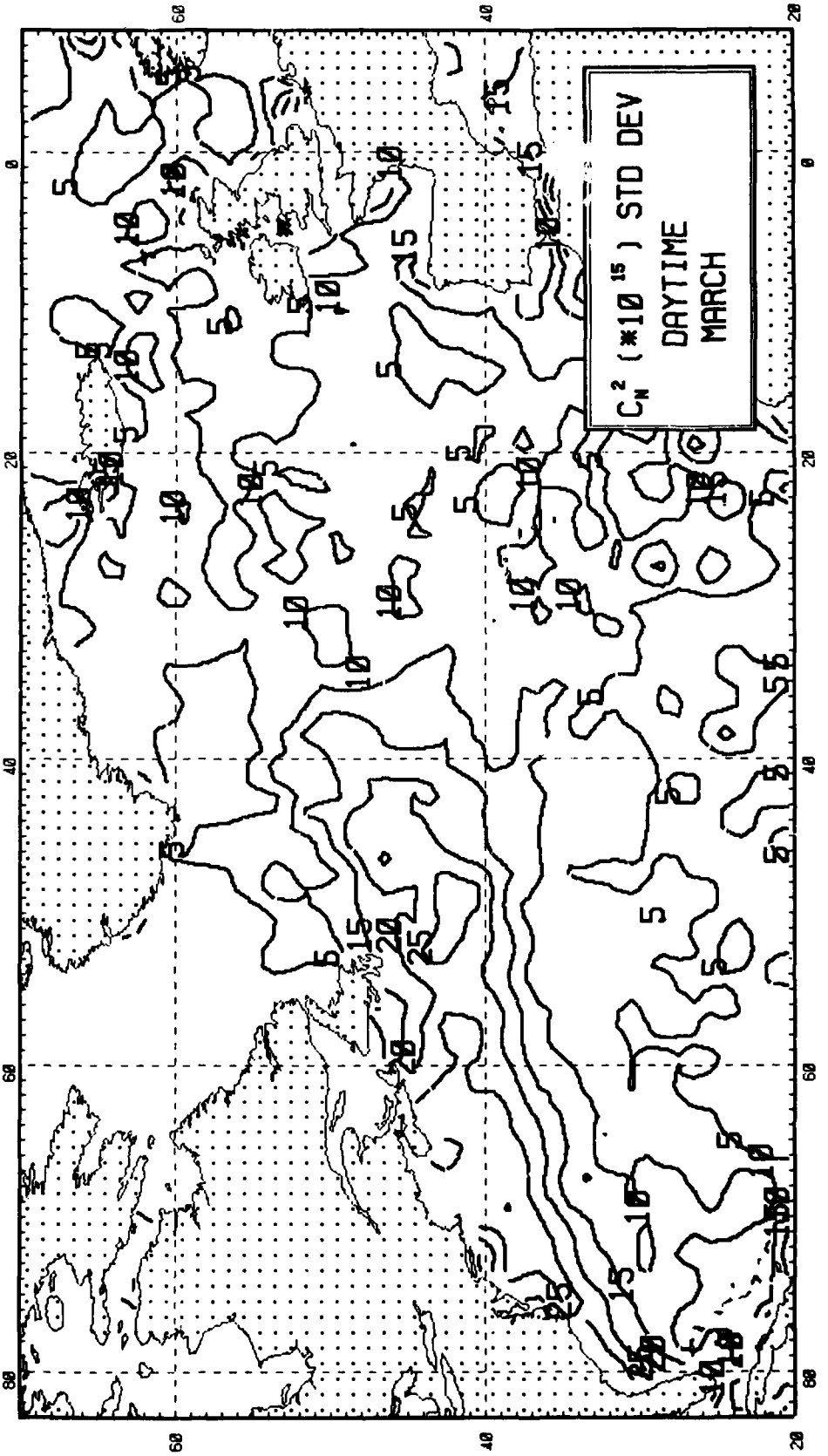


FIGURE 51

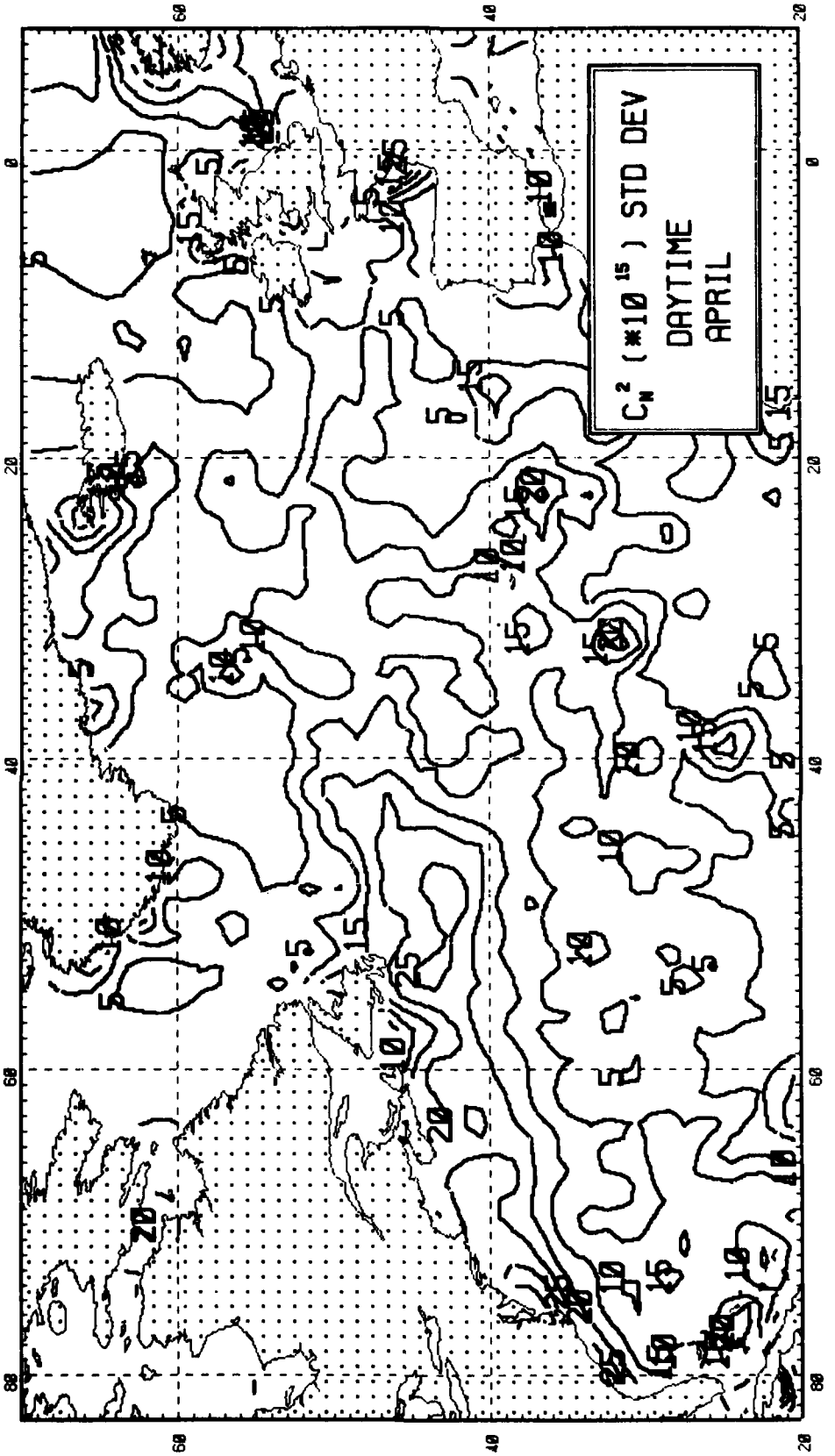


FIGURE 52

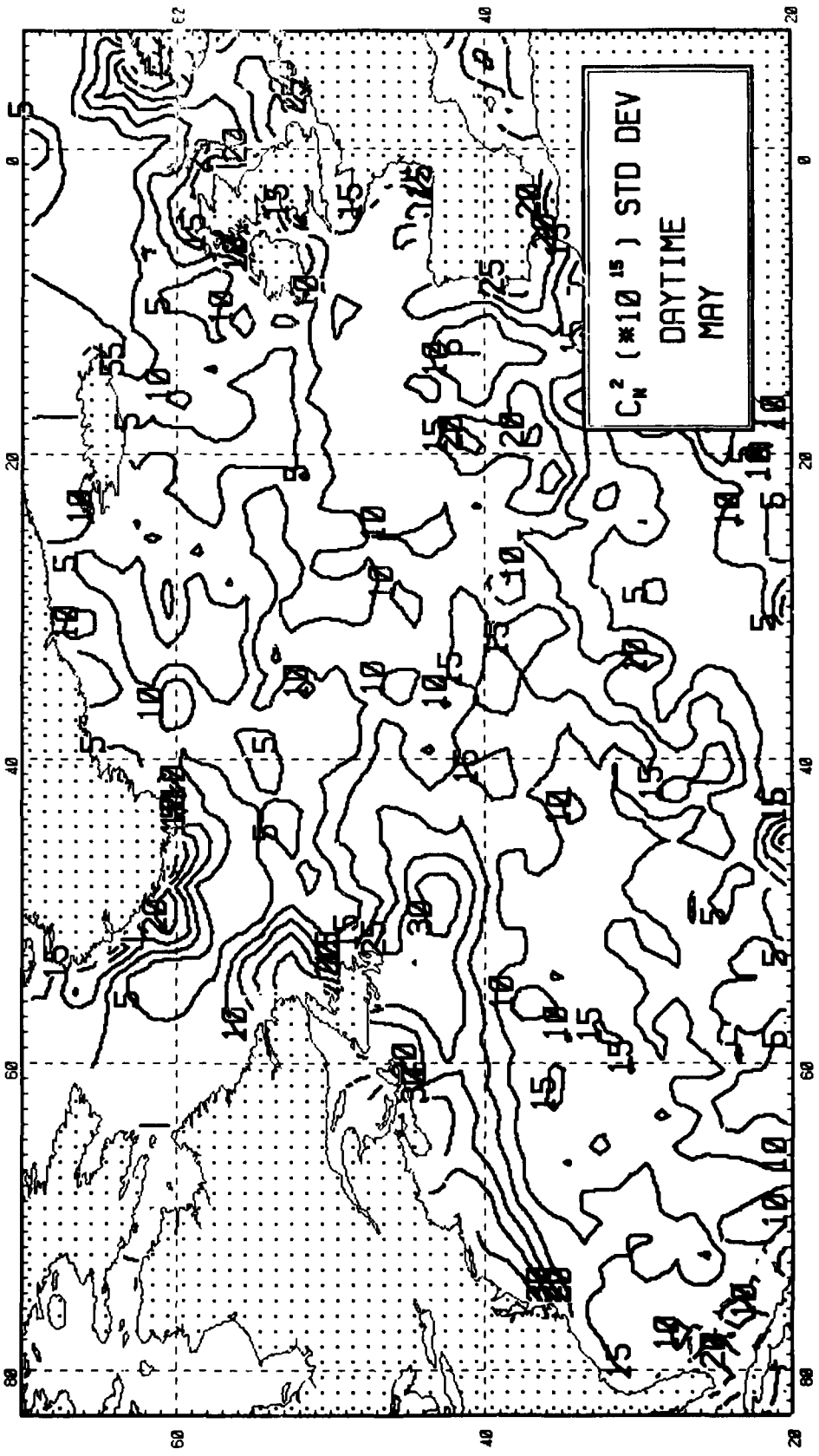


FIGURE 53

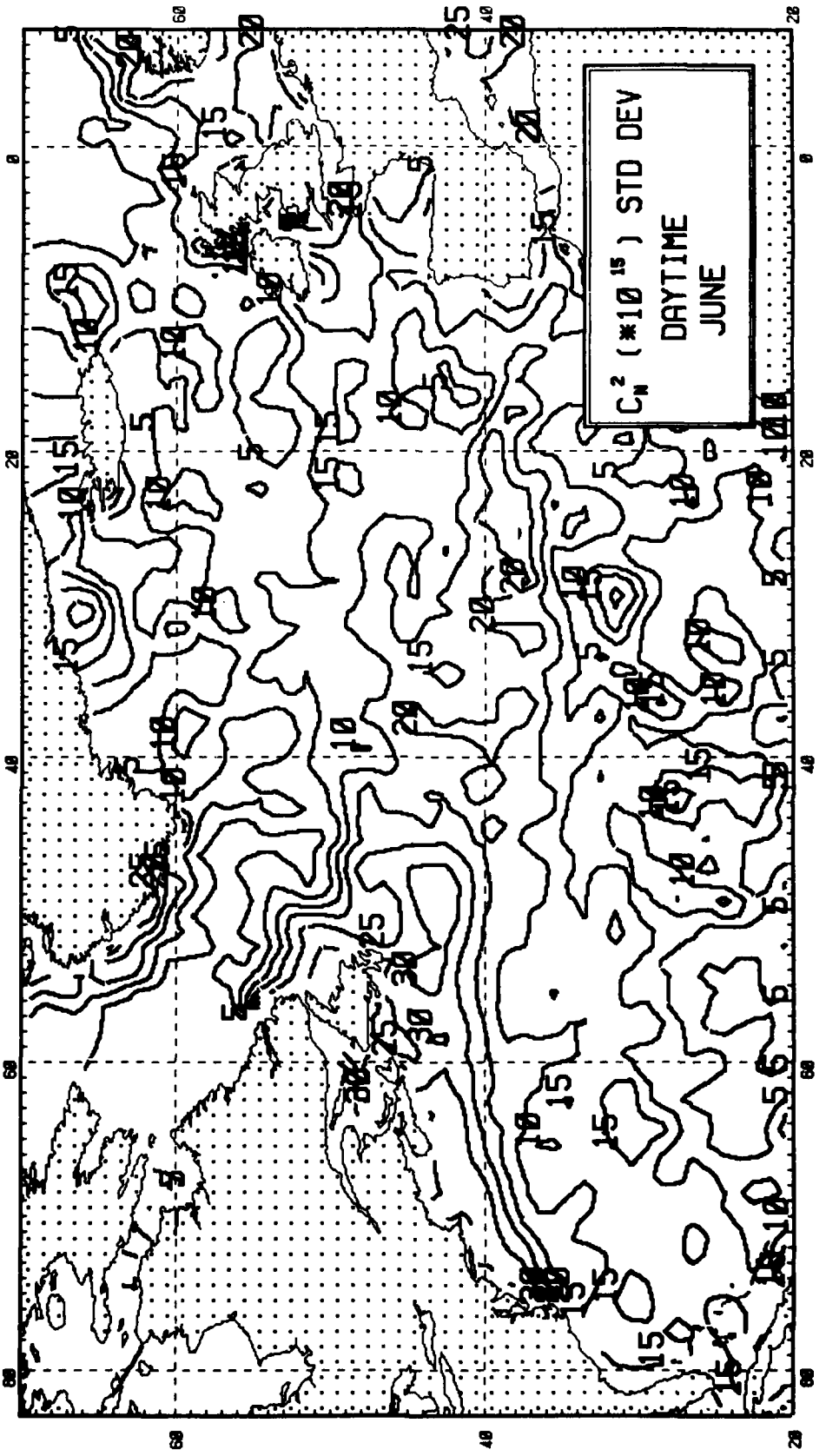


FIGURE 54

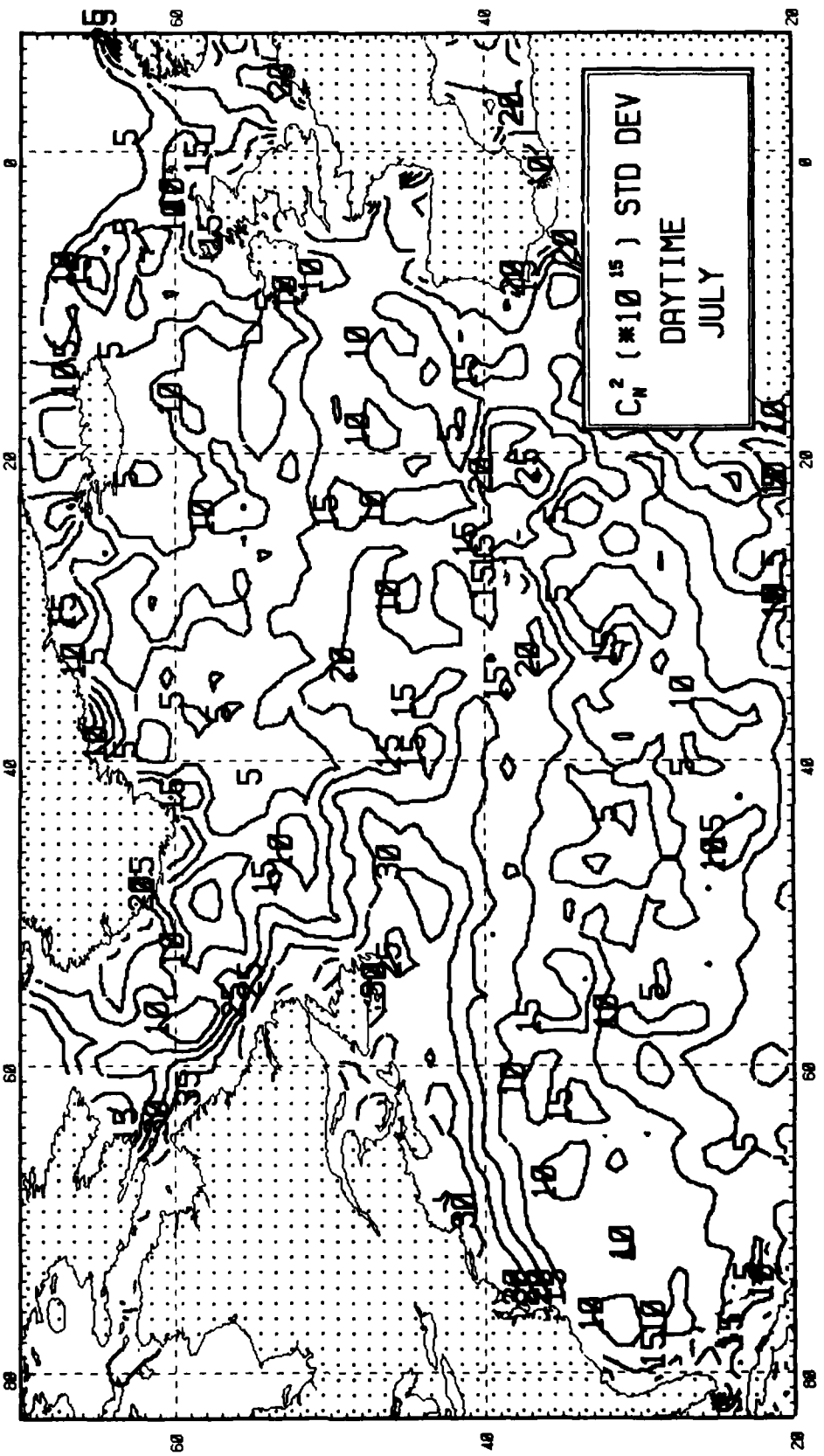


FIGURE 55

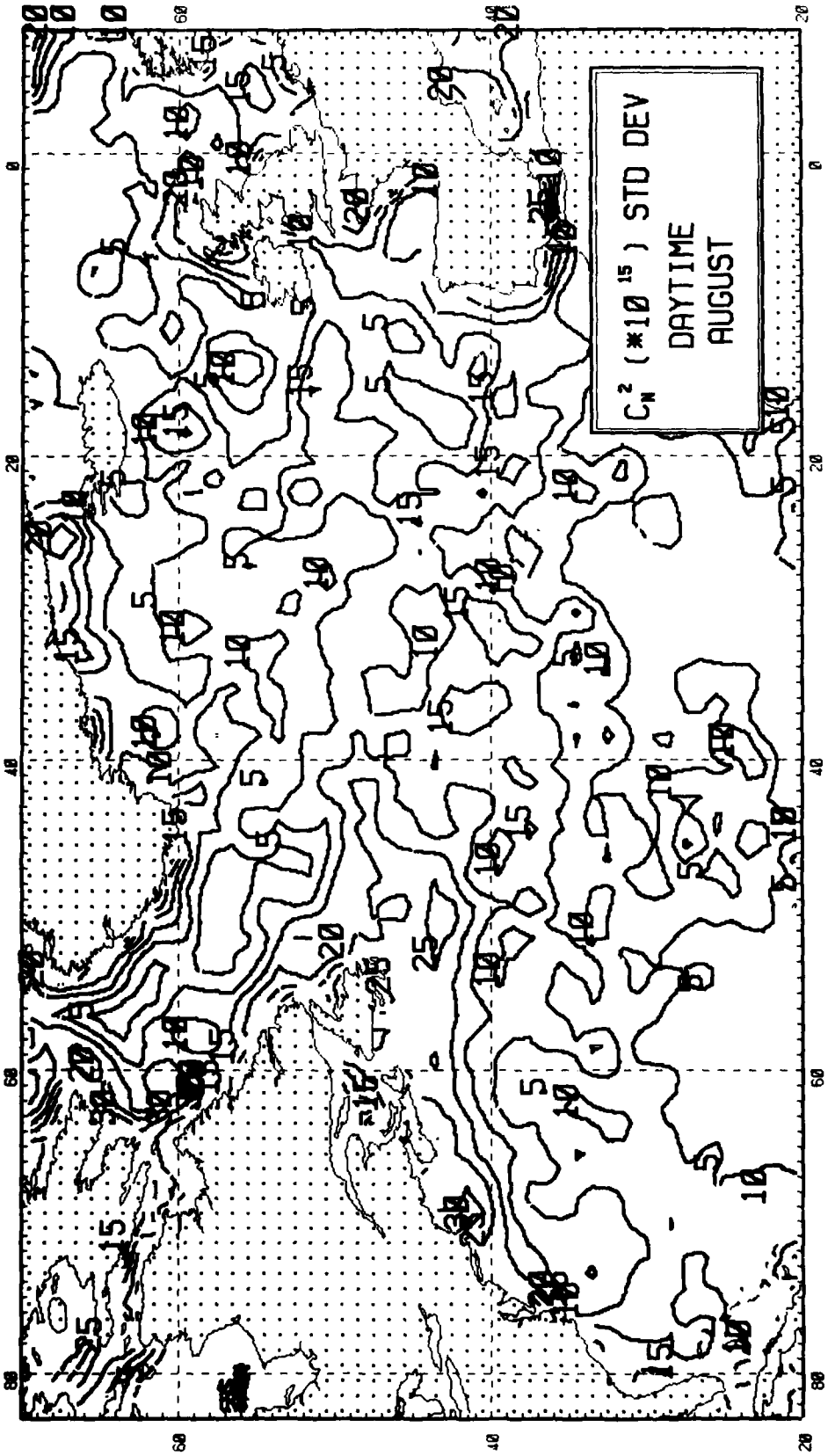
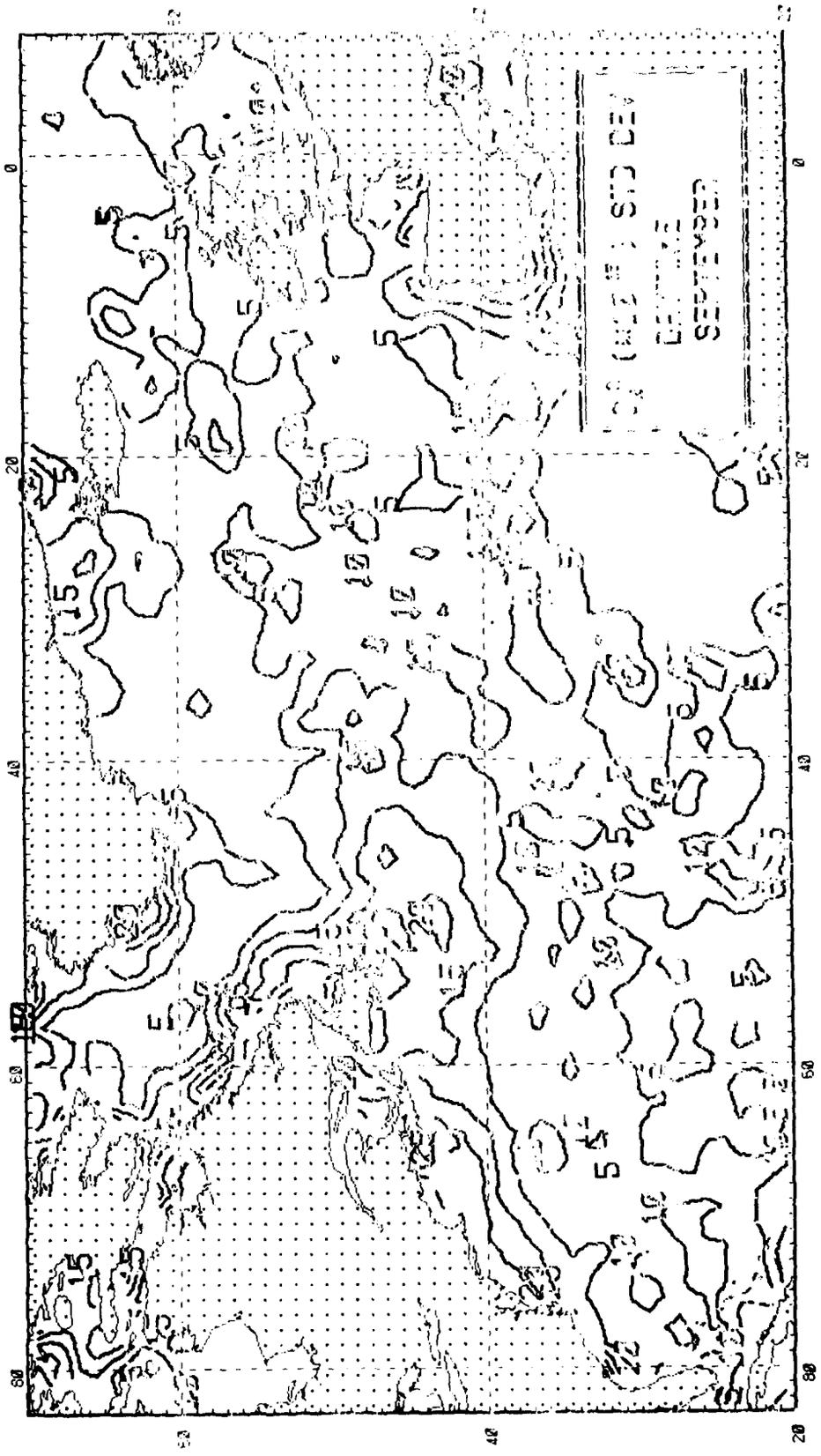


FIGURE 56



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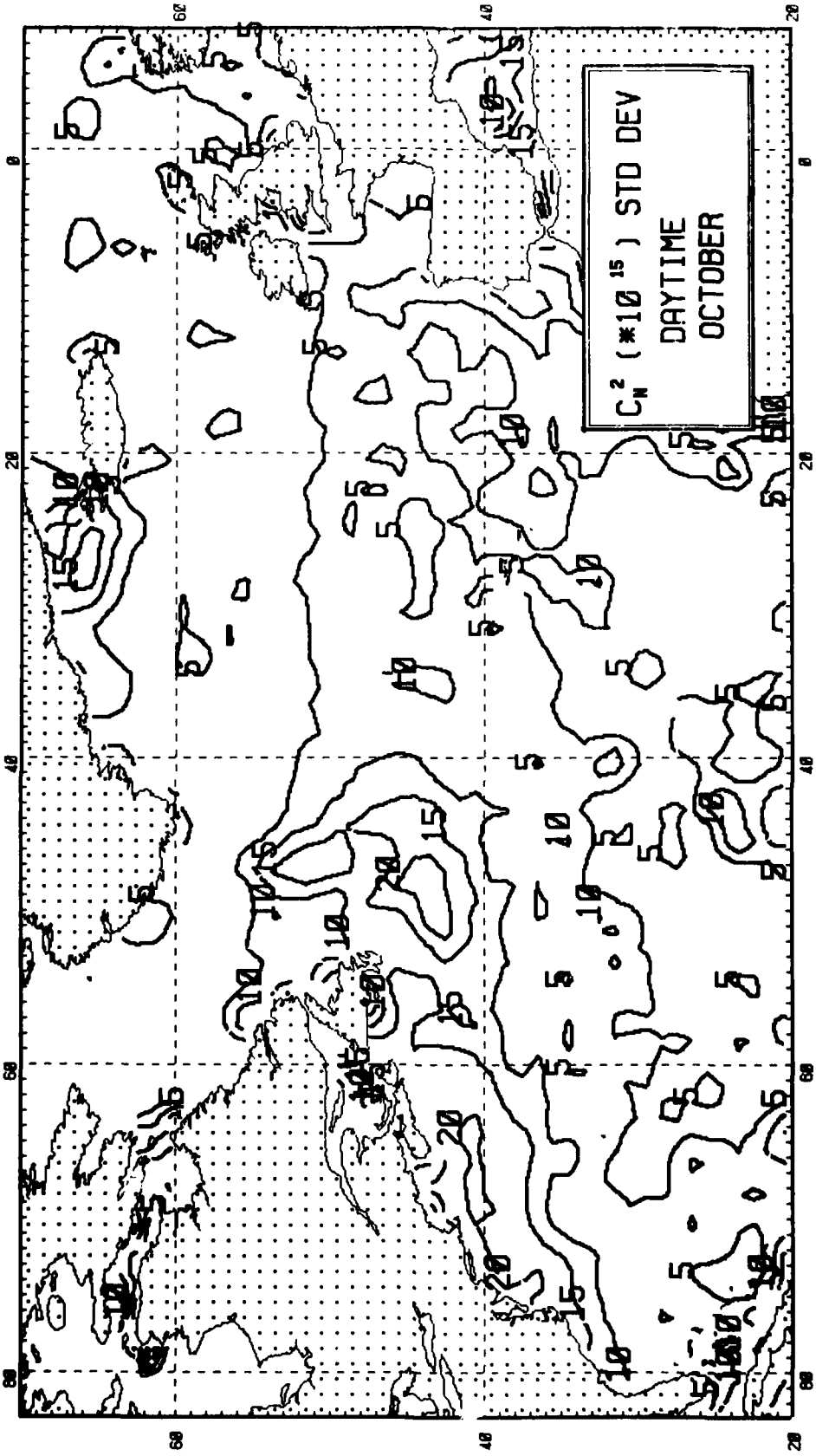

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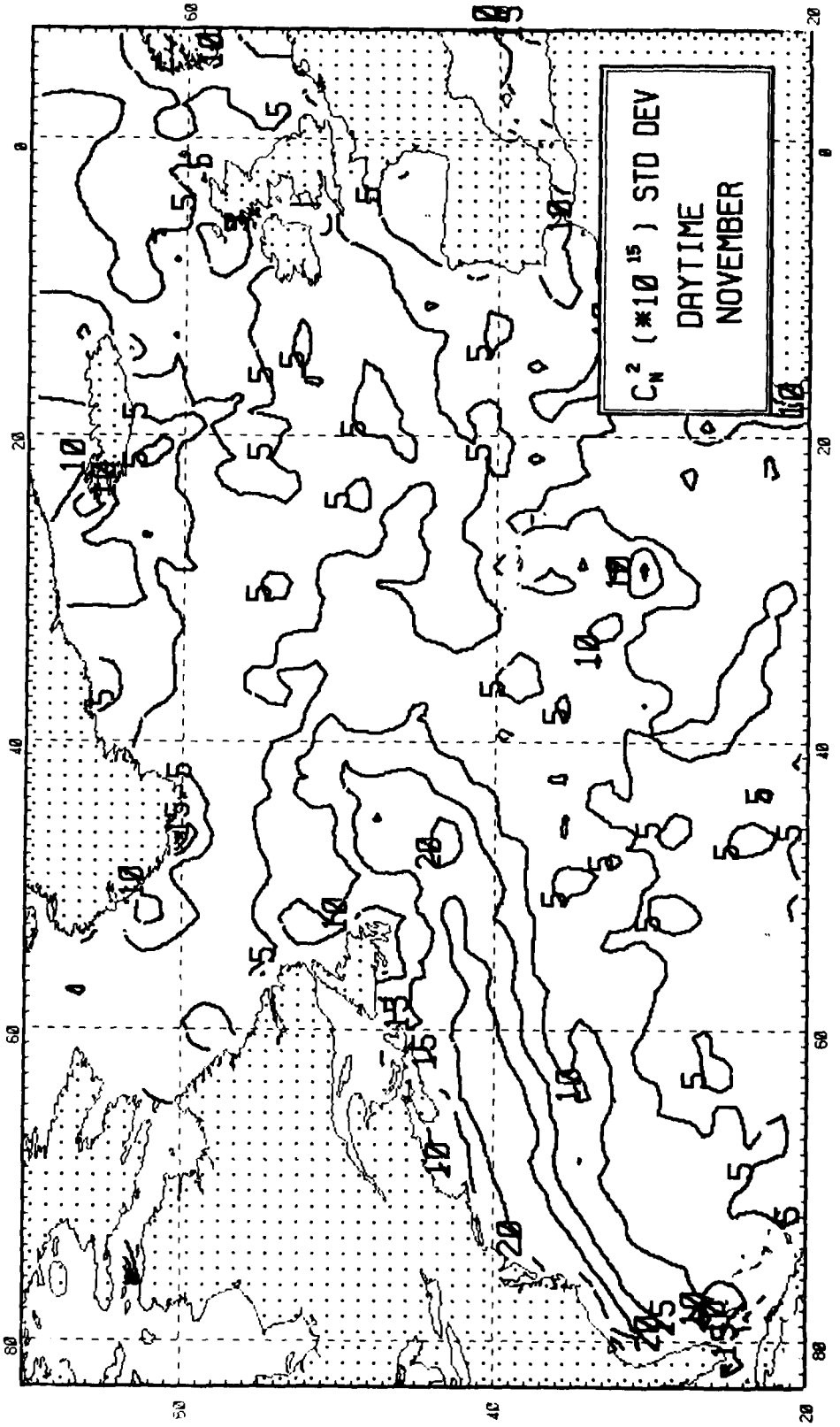

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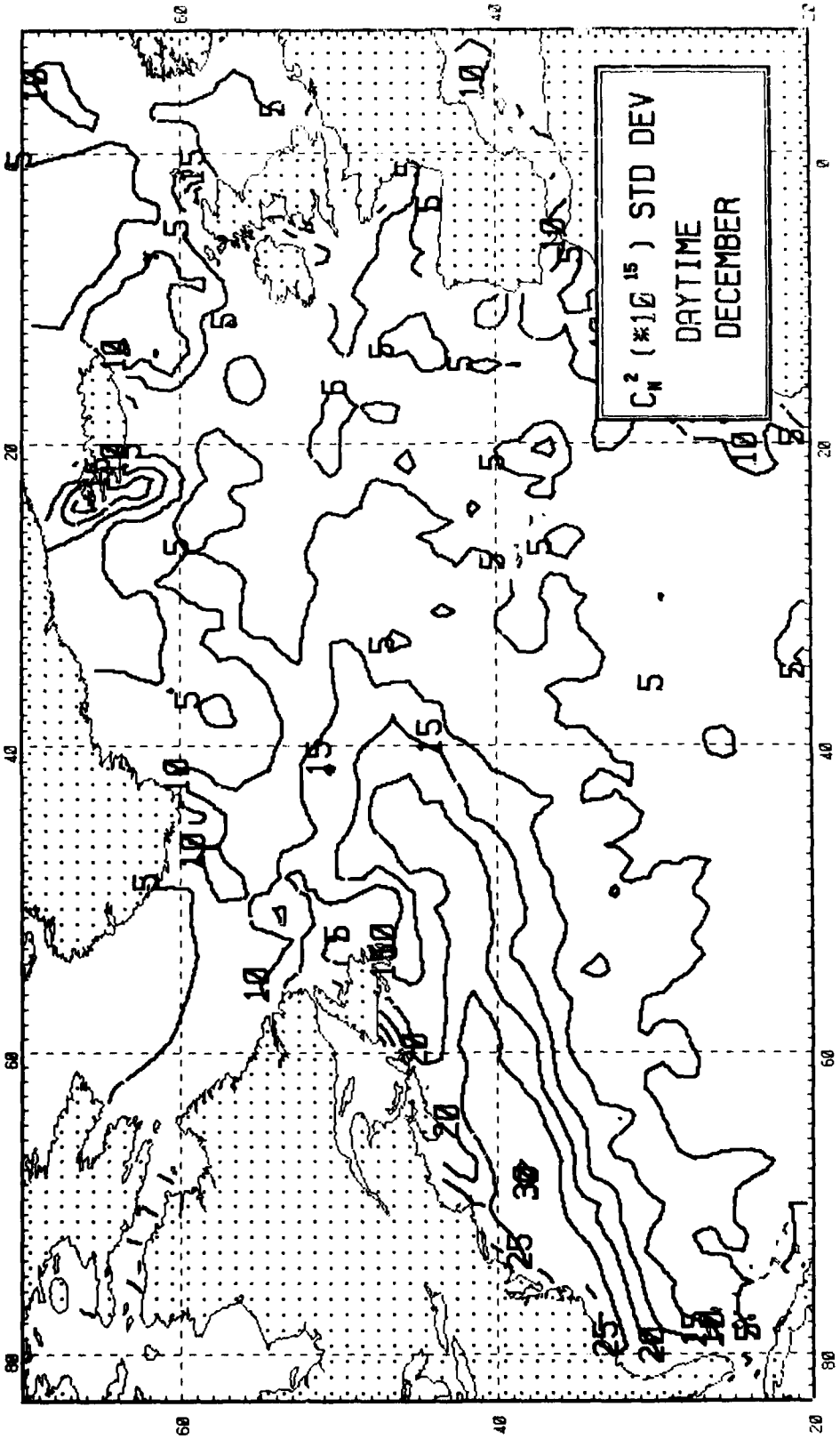

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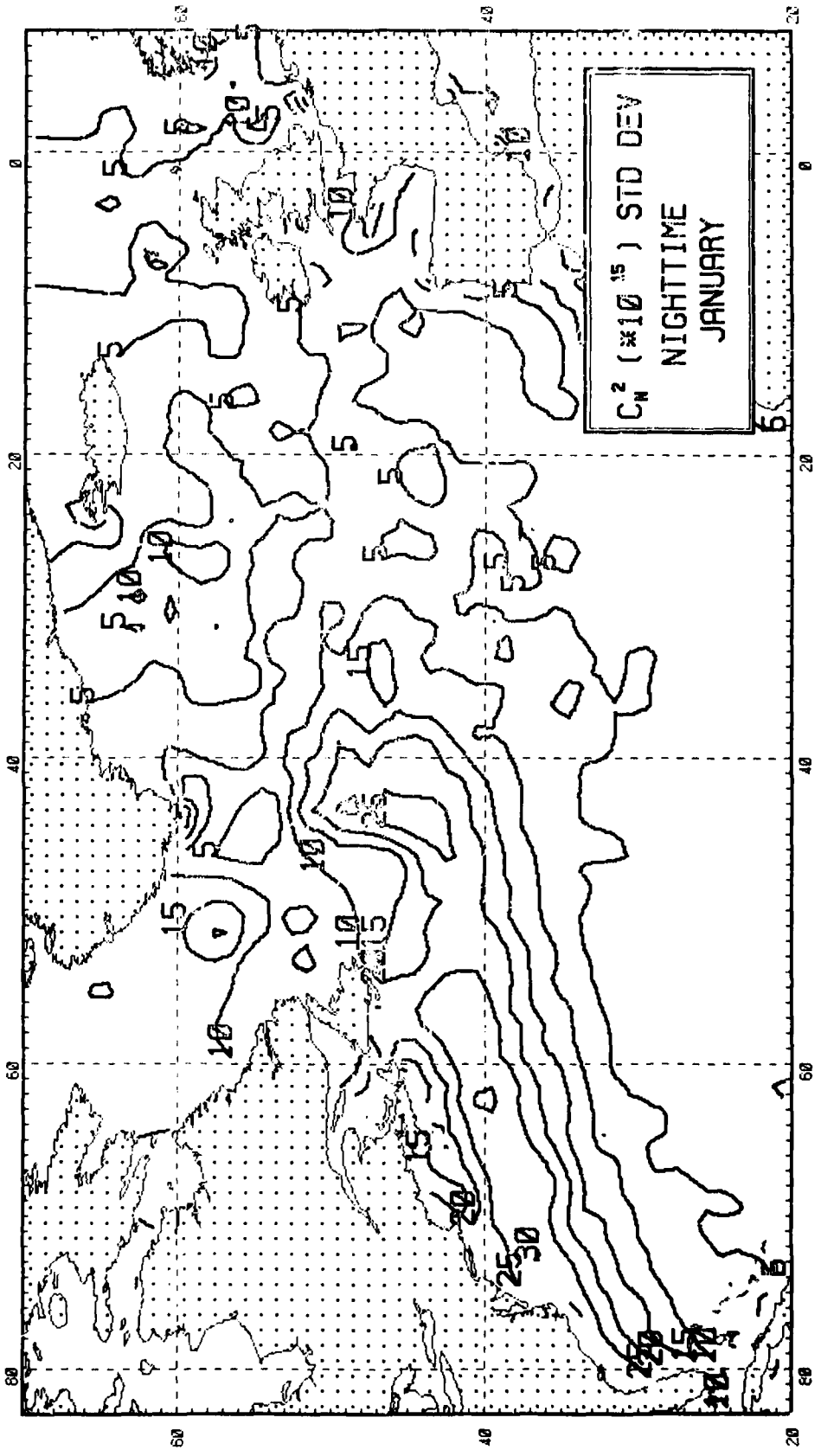

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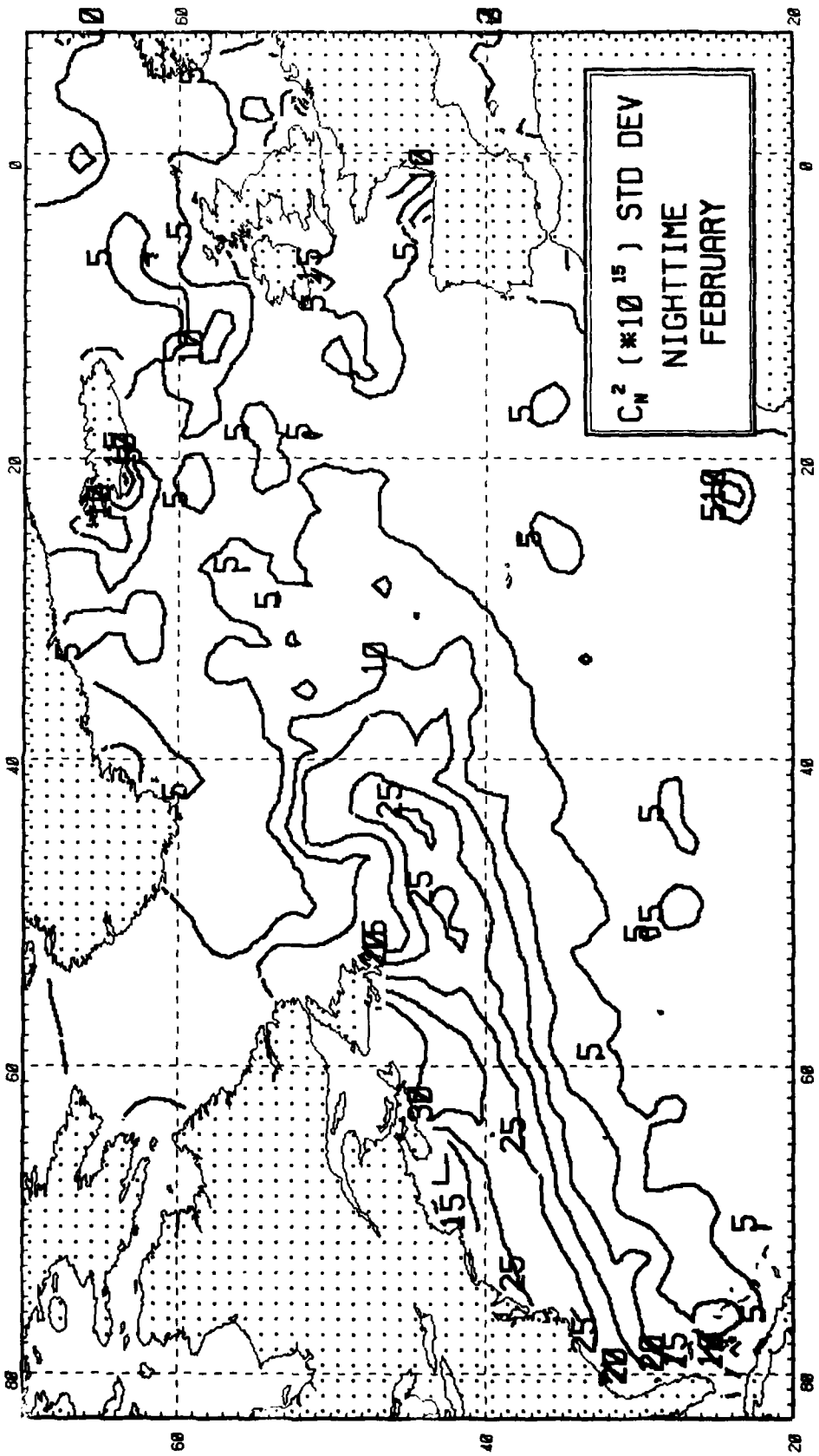

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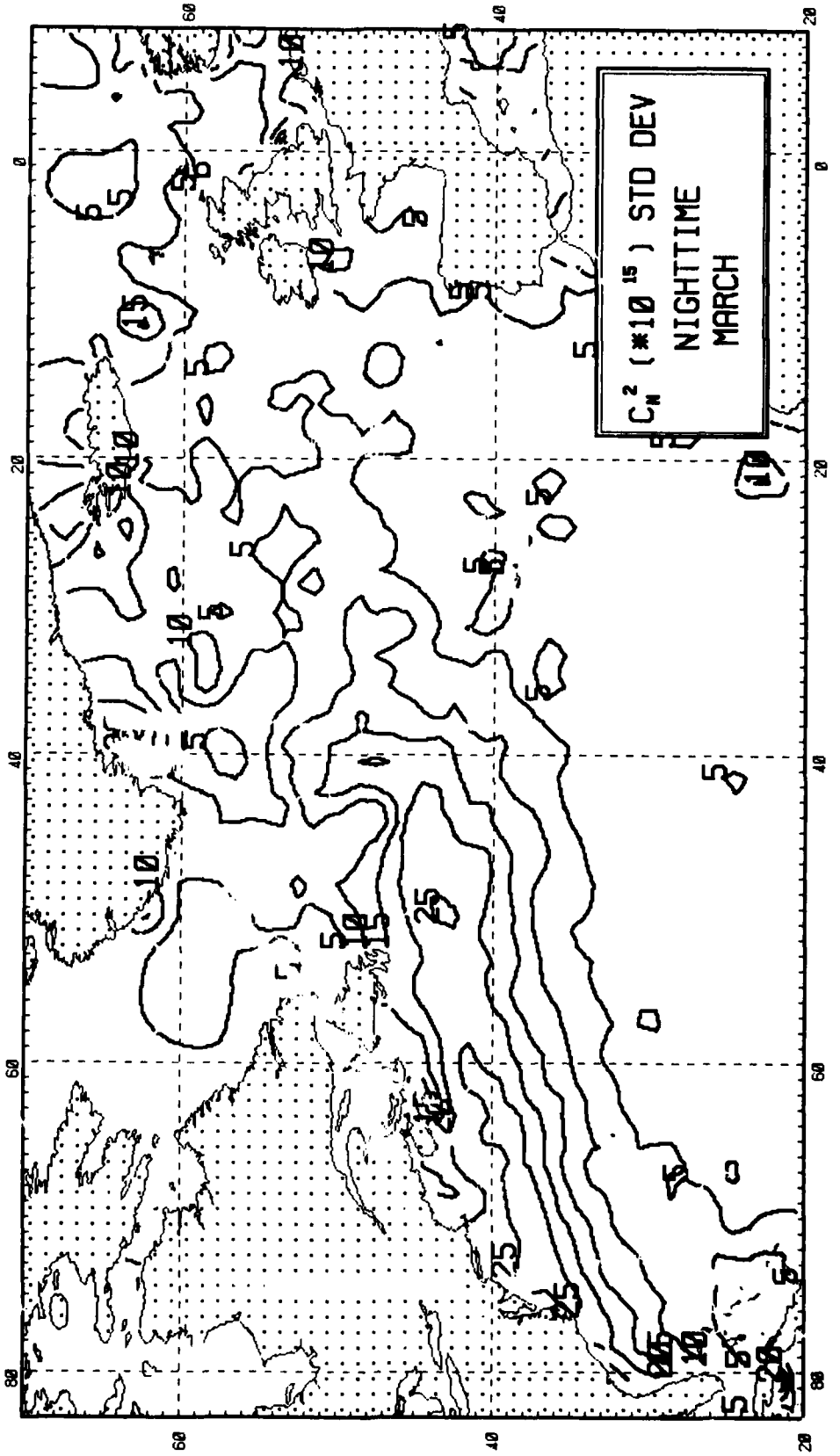

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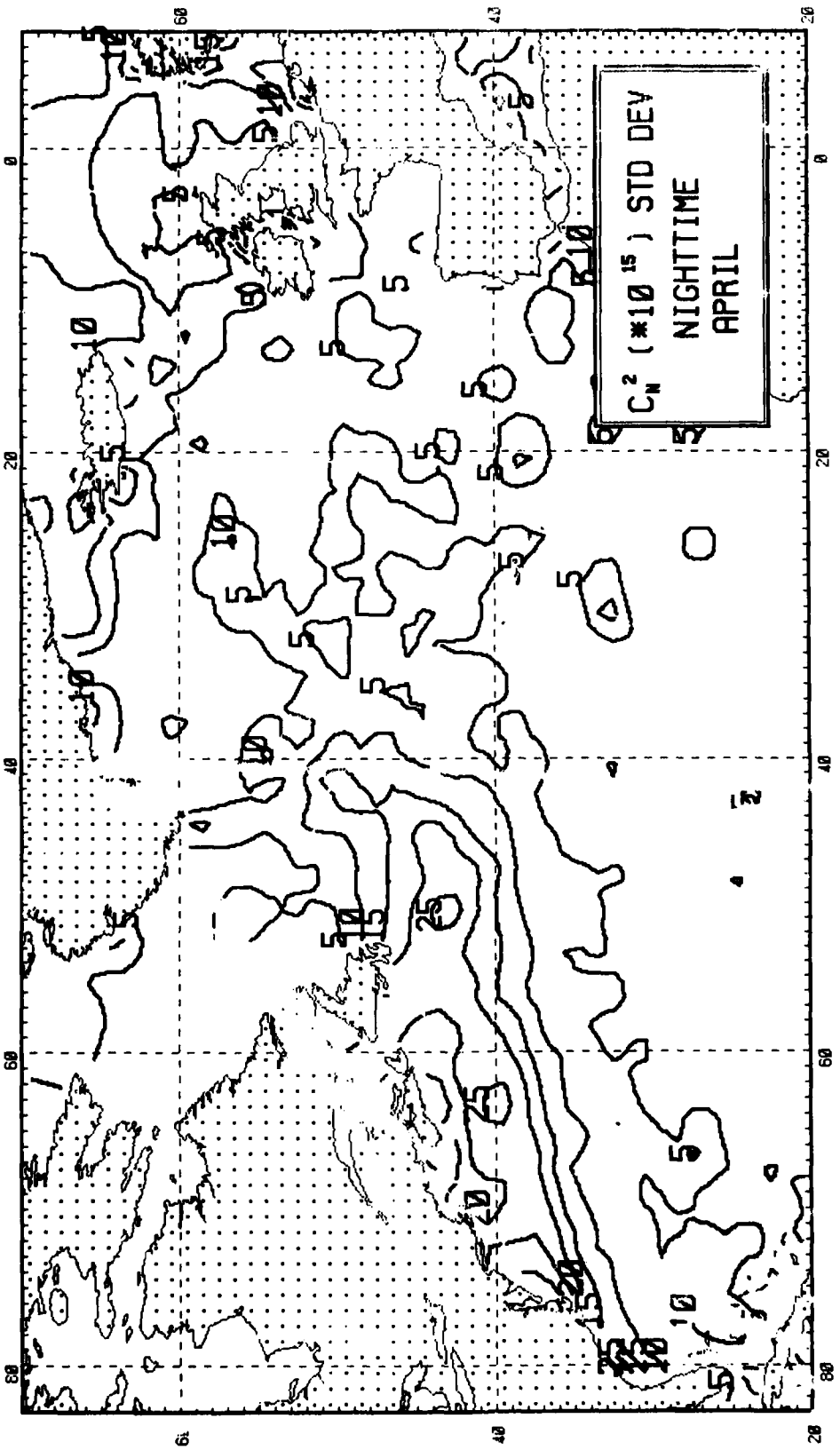

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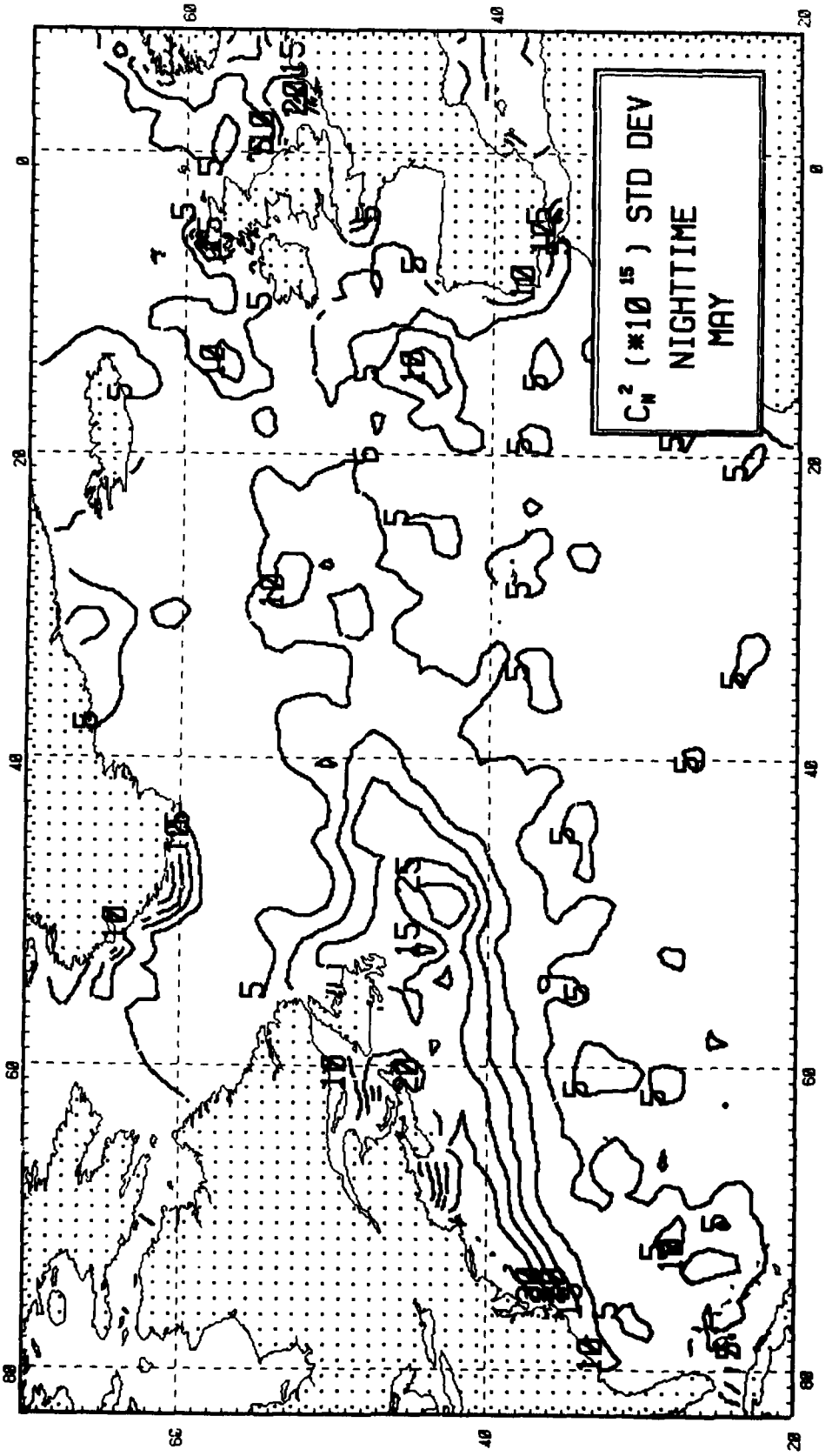

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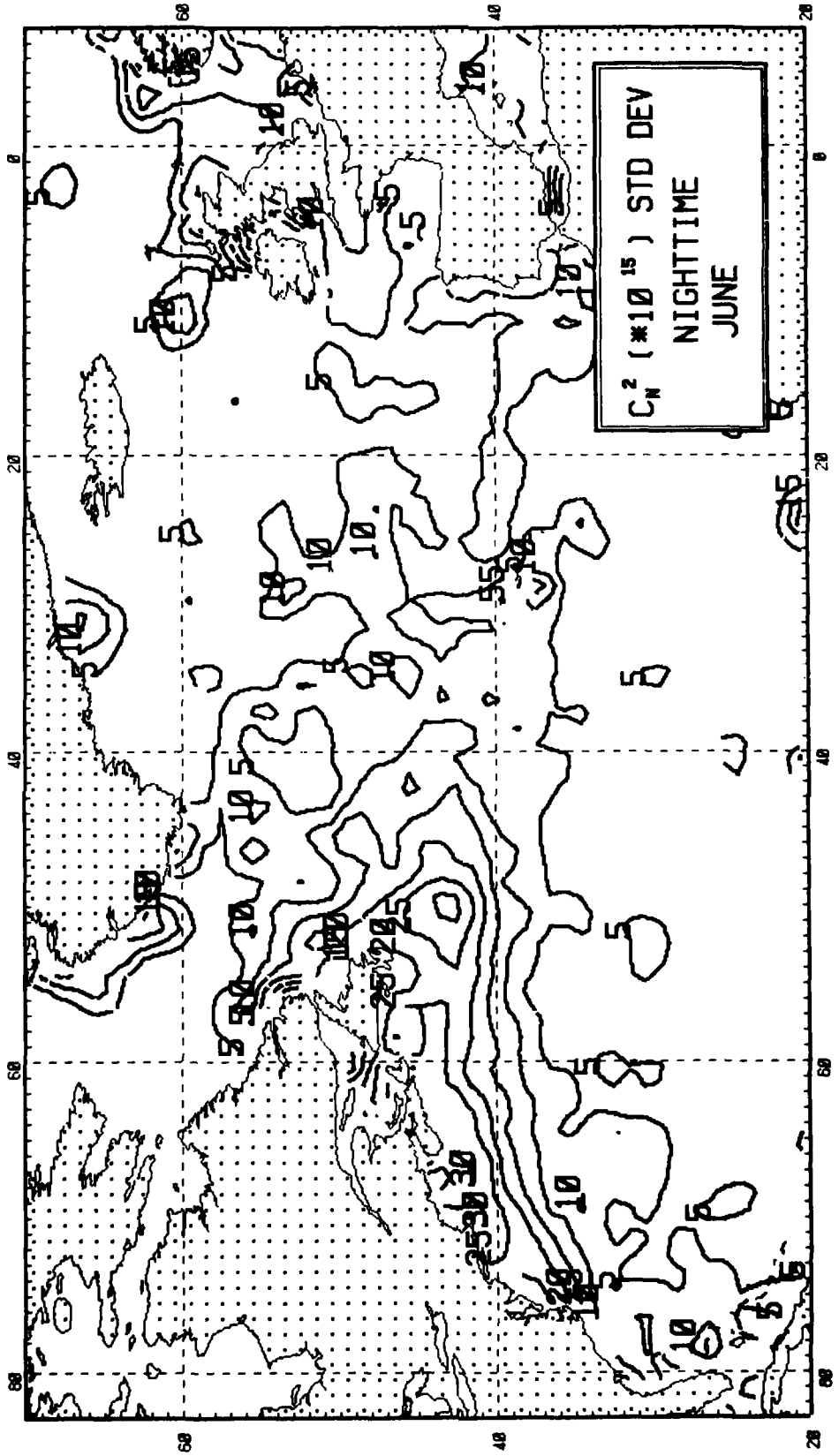
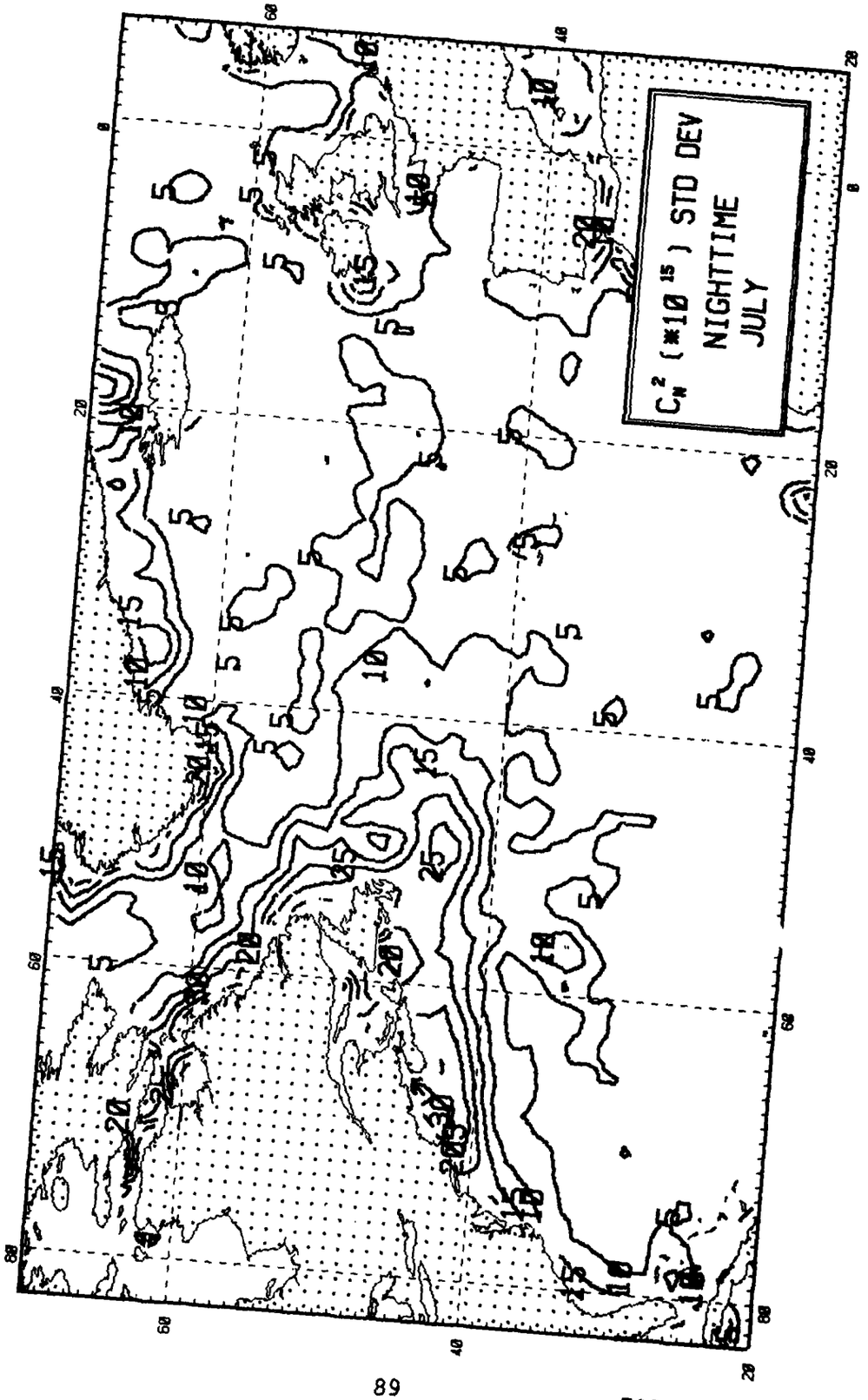


FIGURE 66



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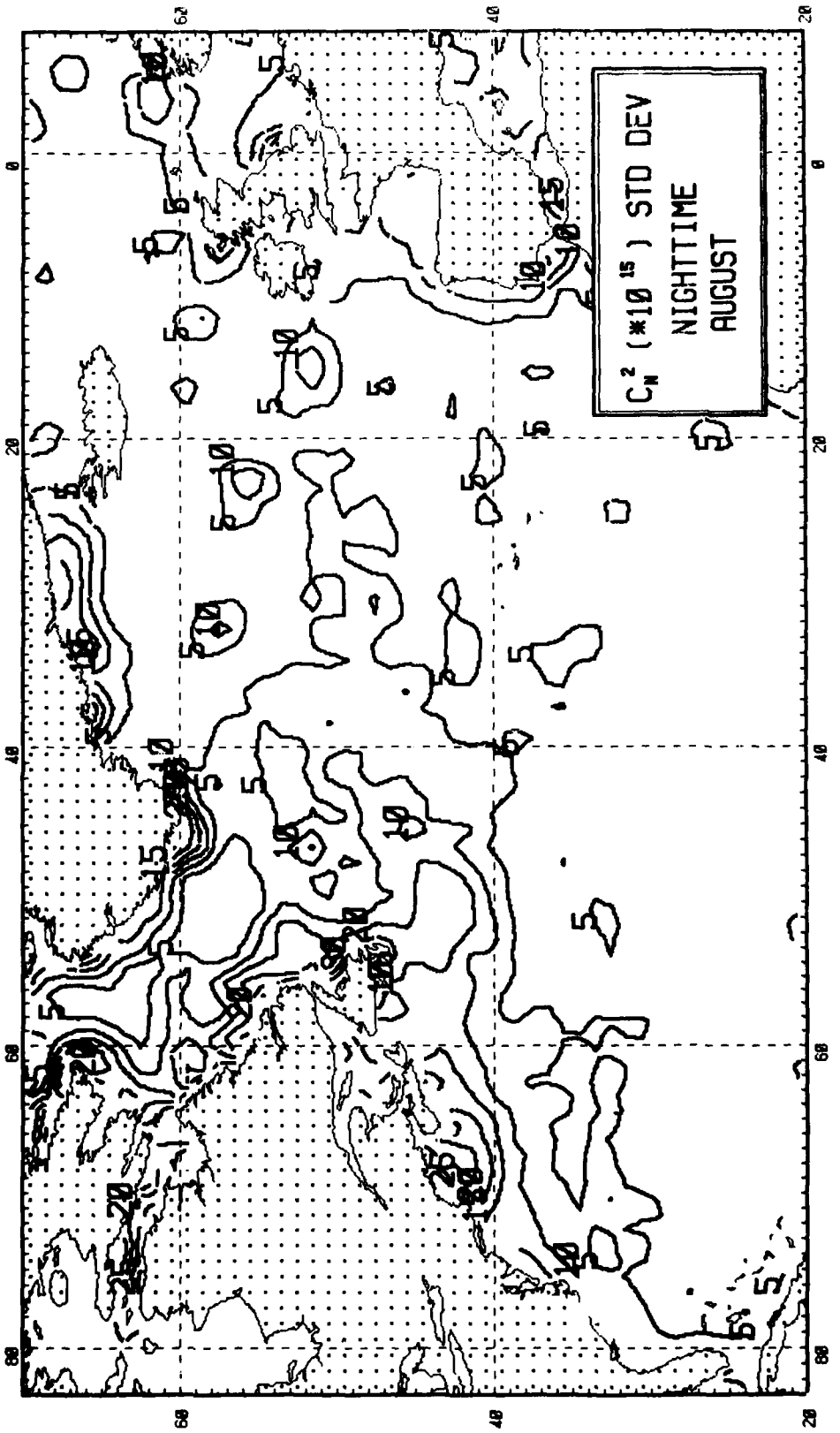

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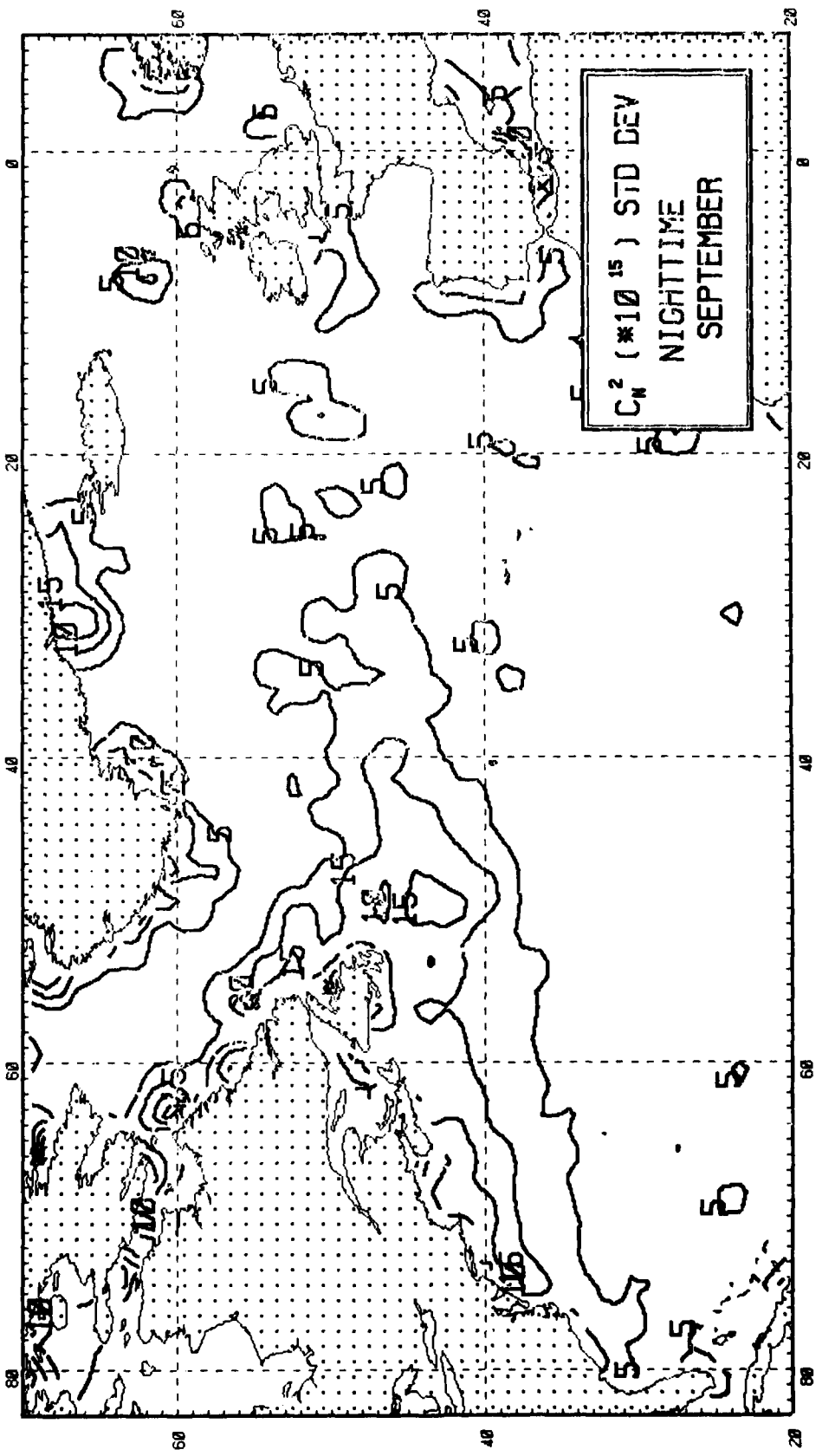

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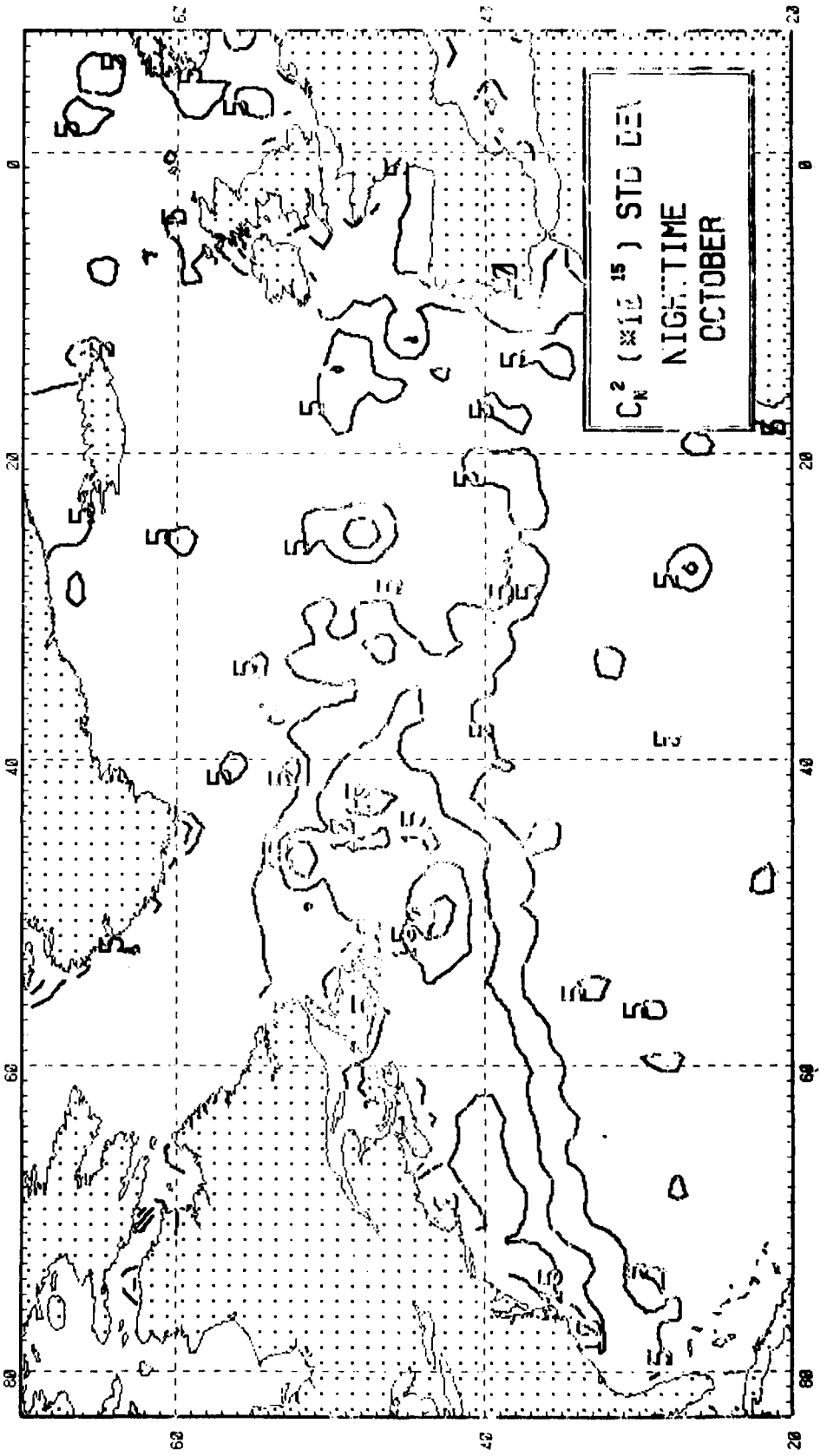

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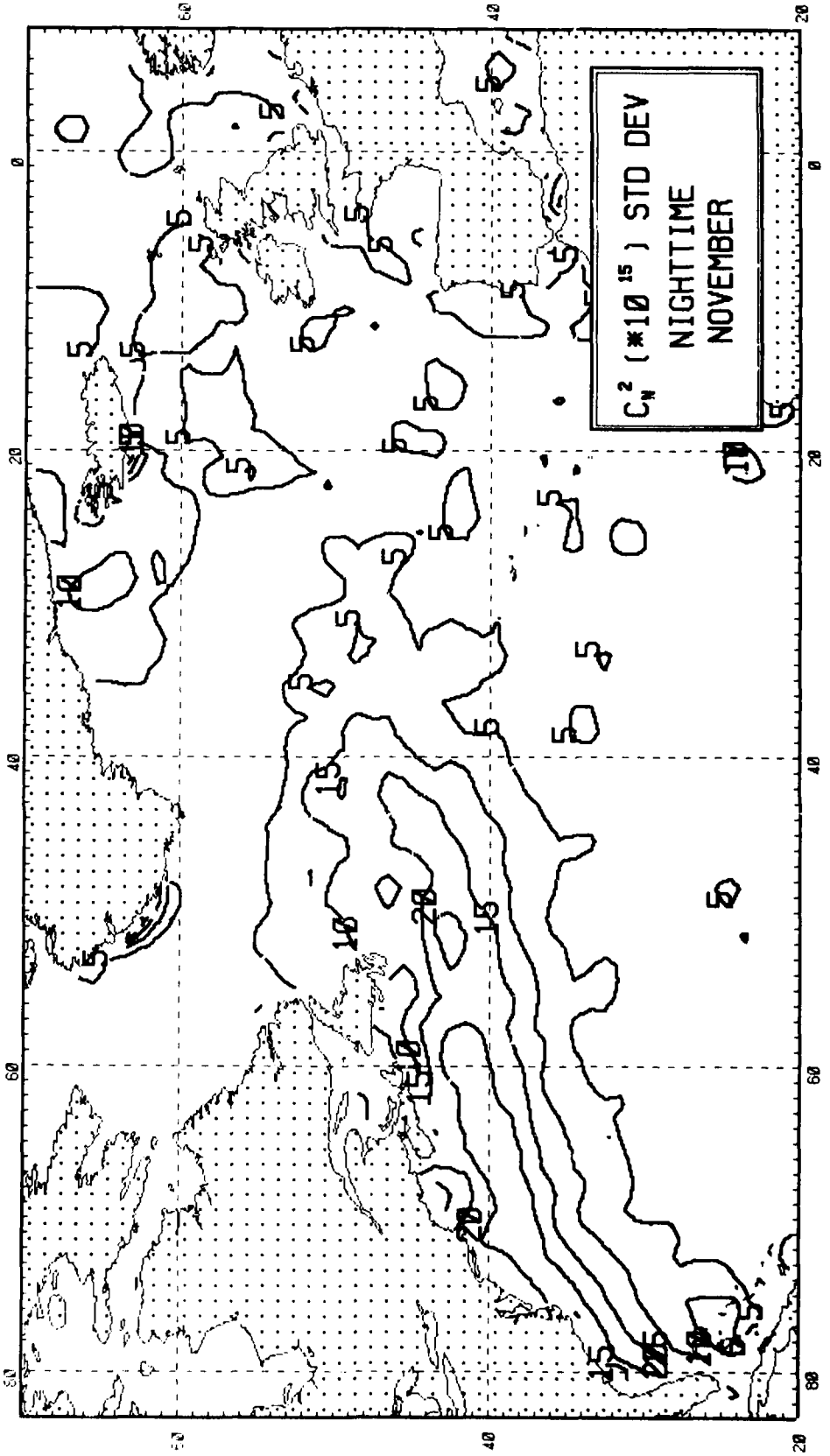

FIGURE 71

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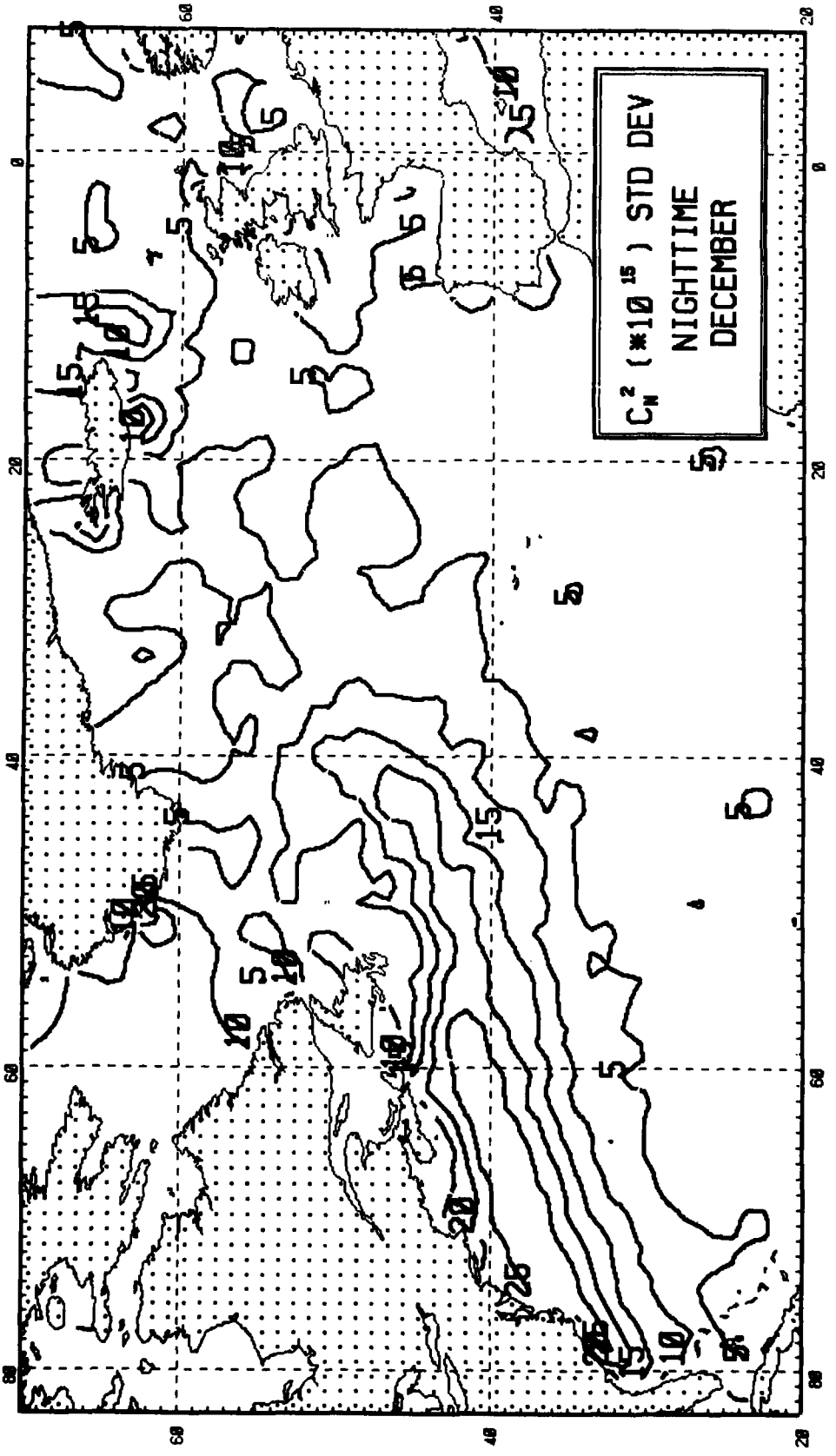

FIGURE 72

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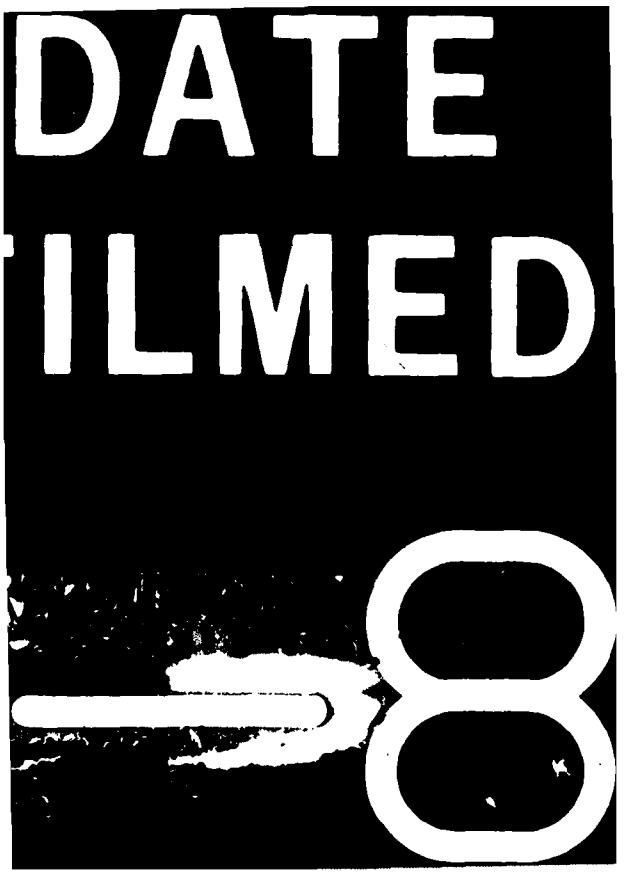
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